Industrial Symbiosis: Introduction, History and Development

Michael Martin, PhD
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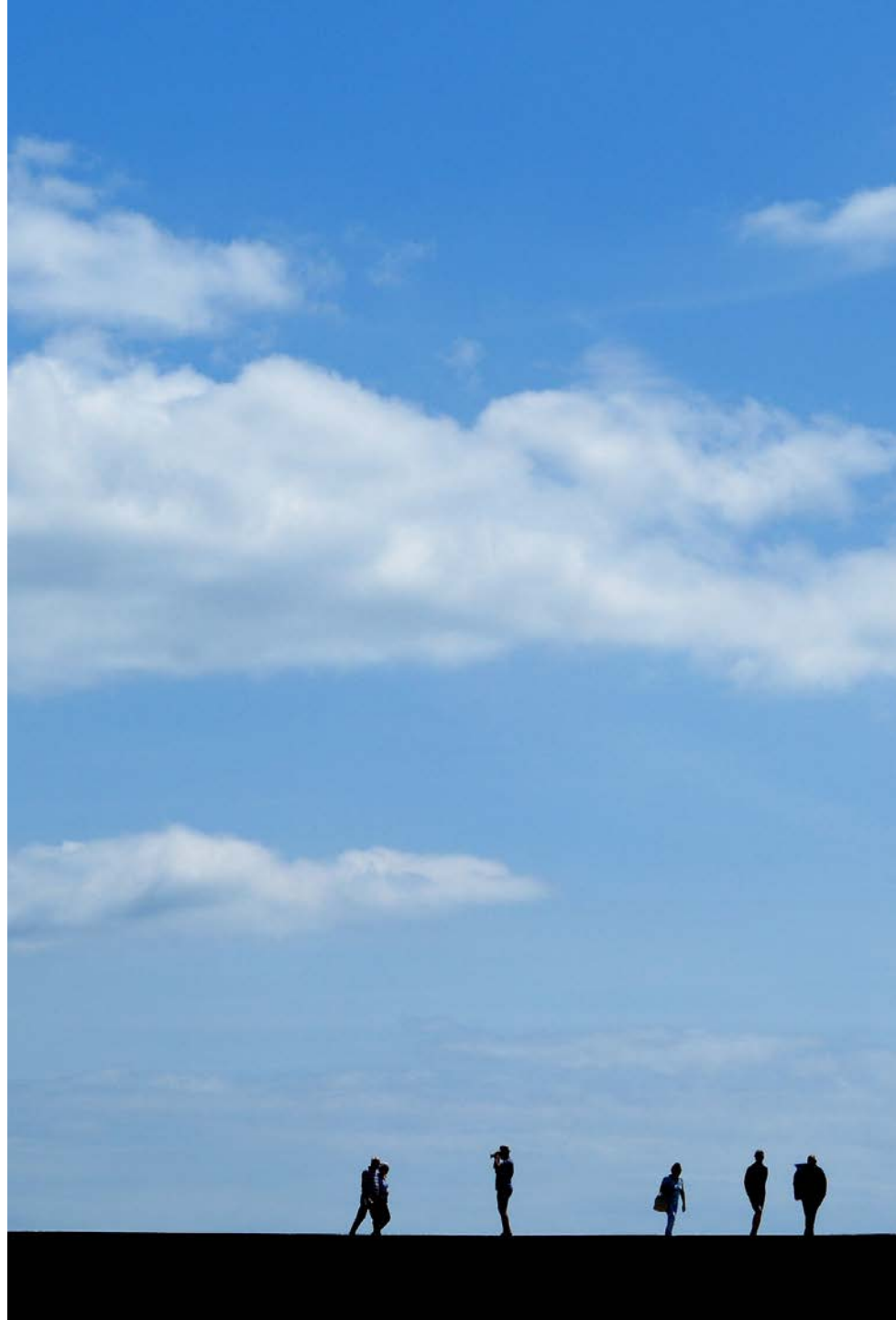
Agenda

- About Michael
- Intro to Industrial Symbiosis
- The CE
- History of the Concept
  - Industrial Ecology
  - Industrial Symbiosis
- Developing Research Area
- Value of Industrial Symbiosis
- Intro to next session

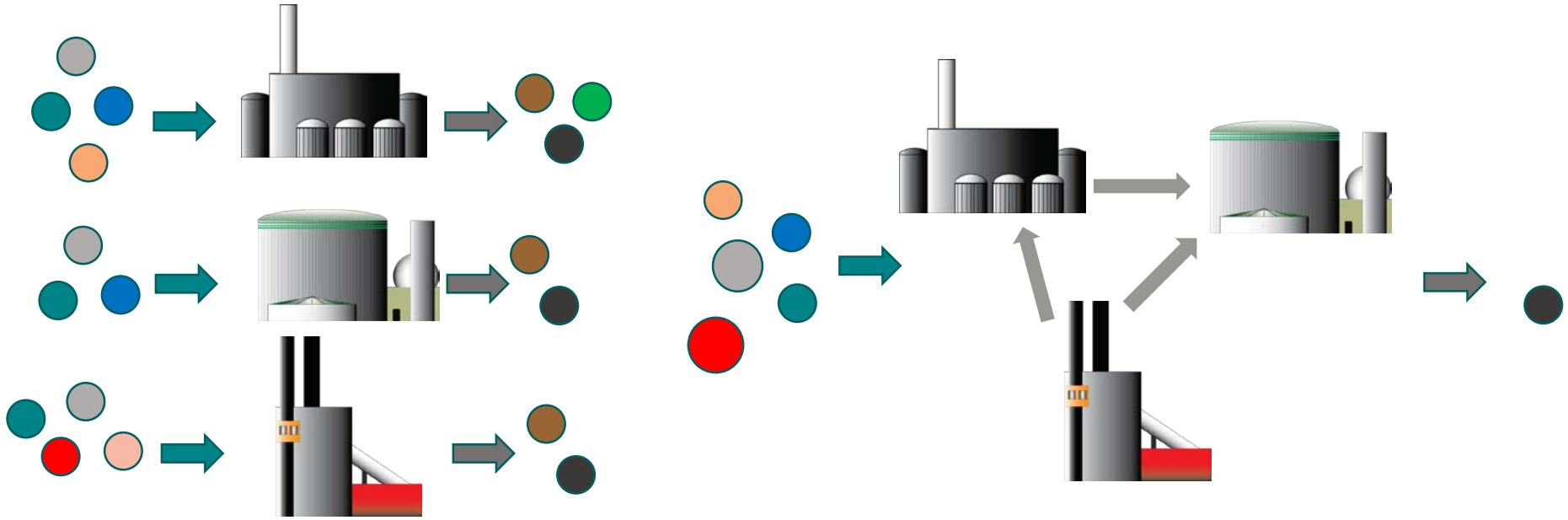


About Me

- Senior Researcher, IVL Swedish Environmental Research Institute, Life Cycle Management
  - Industrial symbiosis, Food, Circular Economy, Life Cycle Management
- Affiliated Faculty/Researcher-Department of Sustainable Development, Environmental Science and Engineering (SEED)
- Executive Board, Industrial and Eco-Industrial Development, International Society for Industrial Ecology
- PhD Environmental Systems Analysis and Environmental Management- Linköping University (Industrial Symbiosis and LCA)
- M.Sc. KTH, B.Sc. Michigan Tech. University, USA

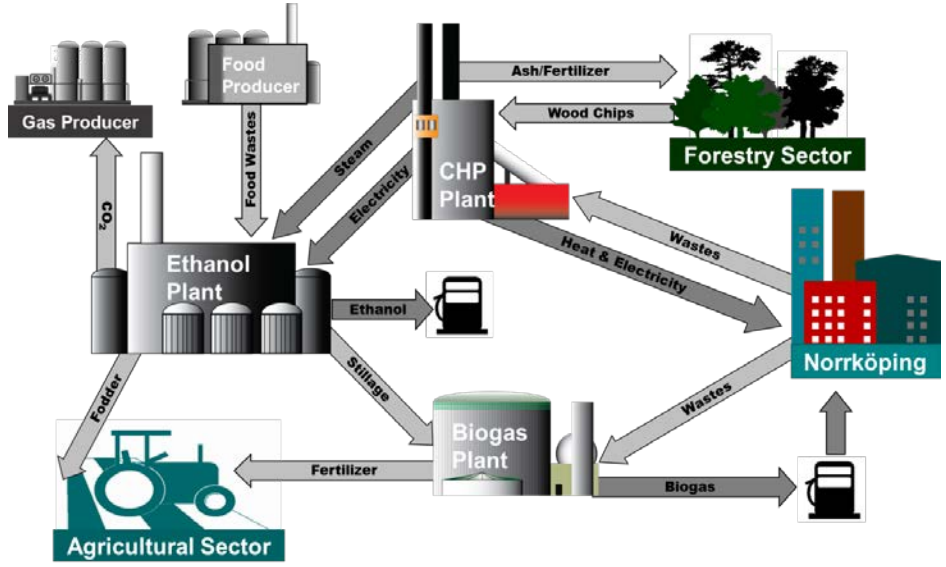
What is industrial symbiosis?

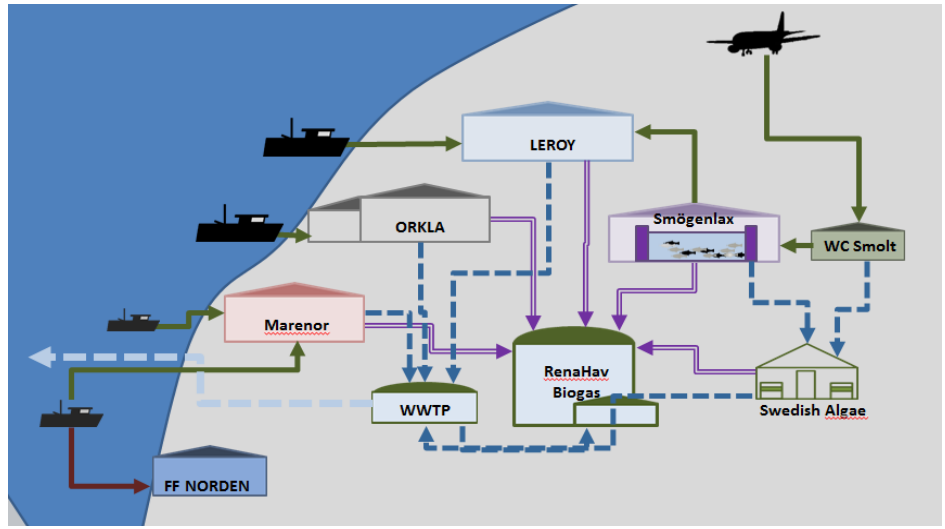
“Industrial symbiosis engages traditionally separate industries in a collective approach to create competitive advantages involving physical exchange of materials, energy, water, and/or by-products.” (Chertow, 2000)



Industrial Symbiosis

- Typically within certain geographic proximity
- Systems approach that identifies ***synergies*** as business opportunities to improve resource utilization
- Synergies are the major mechanism for industrial symbiosis to allow for cross-sectoral and multi-stakeholder resource, knowledge and innovation exchanges





Synergies (Exchanges Vital for IS)

- **By-product synergies:** previously disposed by-products, residues and wastes which are subsequently used as an input for another firm as imminent raw materials, additives or fillers for other firms within different geographical boundaries, e.g. within an defined industrial park, between entities or firms across regions

- **Utility synergies** involve the sharing and management of utilities, including the sharing of energy, water, electricity, heat, joint treatment of emissions as well as recovery and treatment plants

- **Knowledge synergies** are also key to IS networks, which involve the development and deployment of knowledge for processes to create and manage new products, services and markets

The Research Field/Concept

- Within the research field of ***Industrial Ecology…***
- Use different scientific methods to understand:

  How, what, why and whom

- Both qualitative and quantitative approaches/methods to understand the development, potential, performance and dynamics

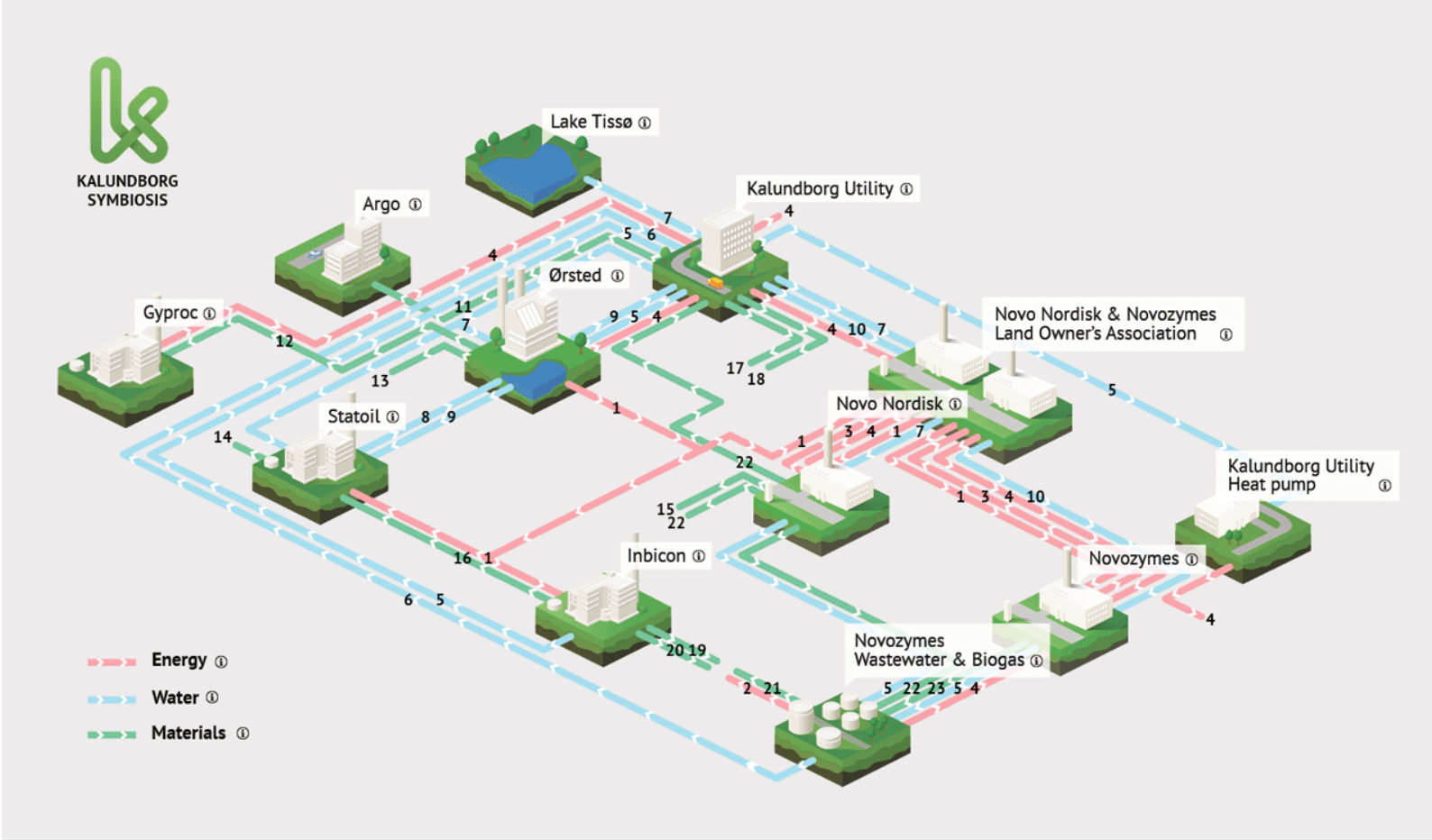
”Science about the forgotten wastes….when the focus was not only the core activities (*Vetenskap om det som blev över …när man inte längre bara kolla på sin kärnverksamhet***)” (Mats Eklund, LiU)**

Many Examples Worldwide

Americas	Europe	Asia/Pacific
• **Keystone Industrial Port Complex (USA)** • **Intervale Food Center (USA)** • **Keystone Industrial Port Complex (USA)** • **Guayama Industrial Symbiosis Network (Puerto Rico)** • **Norte Fluminense IS Network (Brazil)** • **Natura Eco Industrial Park (Brazil)** • **Altamira-Tampico industrial corridor (Mexico)**	• NISP (UK) • Händelö IS Network (Sweden) • Harjavalta Industrial Eco-Park (Finland) • **Kalundborg (Denmark)** • Kaiserbaracke Industrial Park (Belgium) • Rotterdam Harbor INES (Netherlands) • Chemical Industrial Park Knapsack (Germany) • Deux Synthe Industrial Park (France)	• Ulsan Eco-Industrial Park (Korea) • Kwinana Industrial Area (Australia) • Lubei National Eco-industrial Demonstration Park (China) • Suzhou Industrial Park (China) • Nanjangud Industrial Area (India) • Vatva Industrial Park (India) • Eco-Town Kawasaki (Japan)

Kalundborg IS

- Kalundborg, Denmark
- Early example of IS
- Regional Network
- Evolution since the 70s
- ”Text book example”
- Used to study interactions
- Many visits to region



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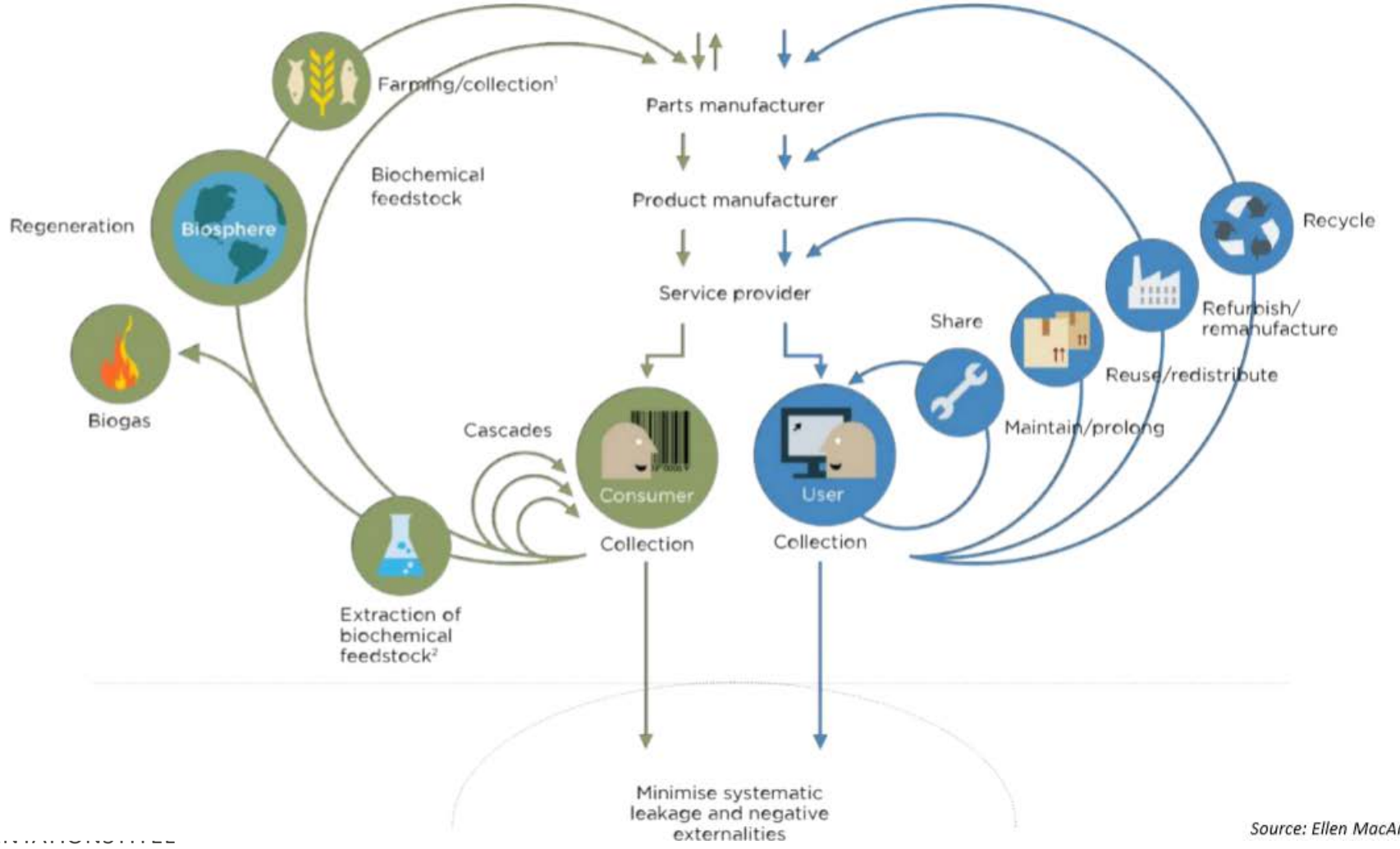
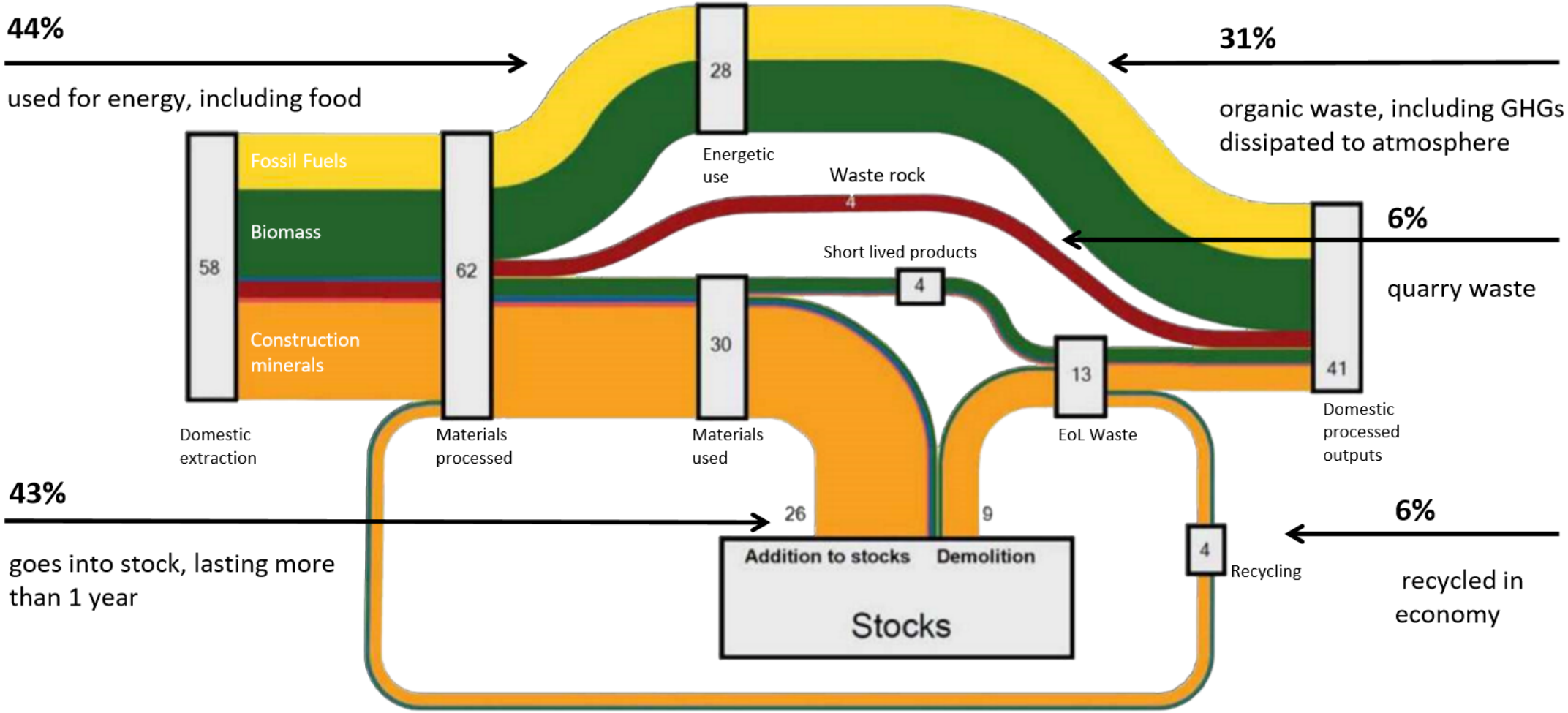
Origins (or re-emergence)

The Circular Economy (CE)



Source: Ellen MacArthur Foundation

Our Current System…



Haas et al. 2015. "How Circular is the Global Economy." Journal of Industrial Ecology

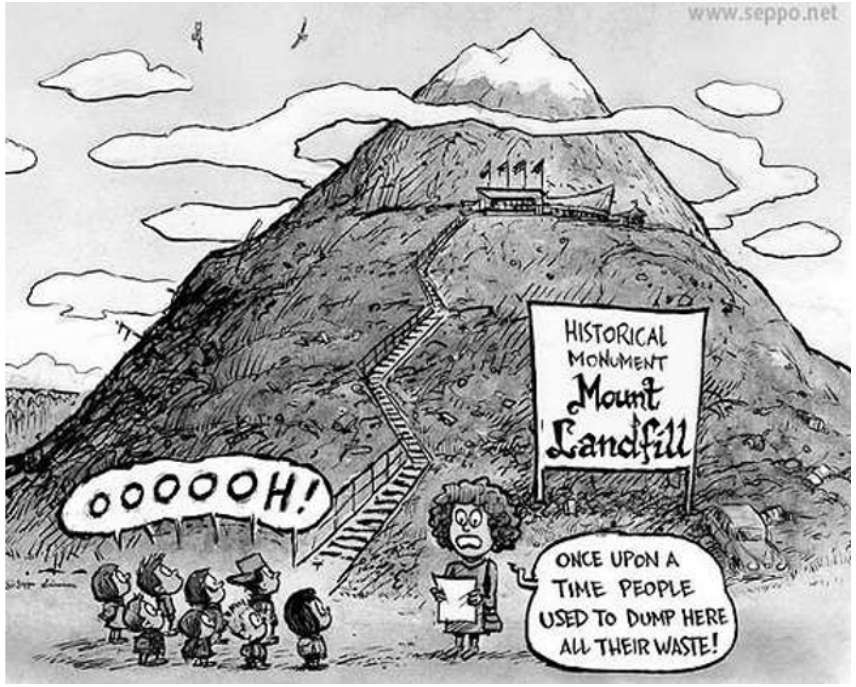
Better before?

- Picture from the 1930s
- Paper/Wood/Fuel/Electricity
- Karälven, Vänern (Sweden)
- Harder to obtain resources
- Efficiency improvements
- Leading to core-business development

Adapted from Eklund, 2018

Systematic Changes Needed

- Local impacts and environmental damage
- Depleting stocks and increasing wastes
- Need for Resource Efficiency
- Increasing view of the value of natural resources and regional development



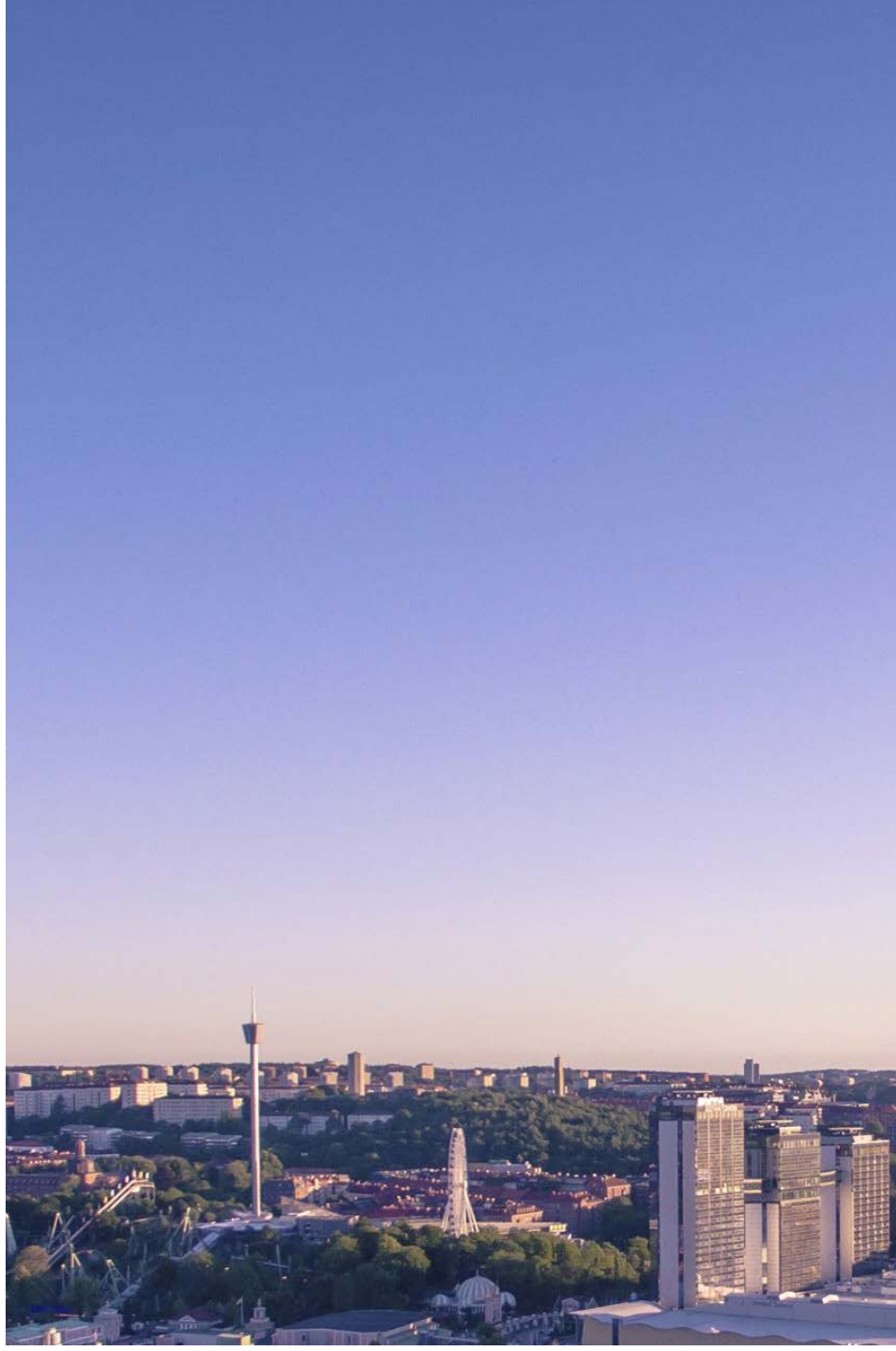
Emerging Research Thoughts/Concepts

- Model Industrial Systems, like Ecological Systems
- Systems Thinking
- Circular Resource Use (No Waste)
- Different Scientific Disciplines (Economics, Ecology, Geogrophy, Production)
- Require multi-disciplinary approaches

Industrial Ecology

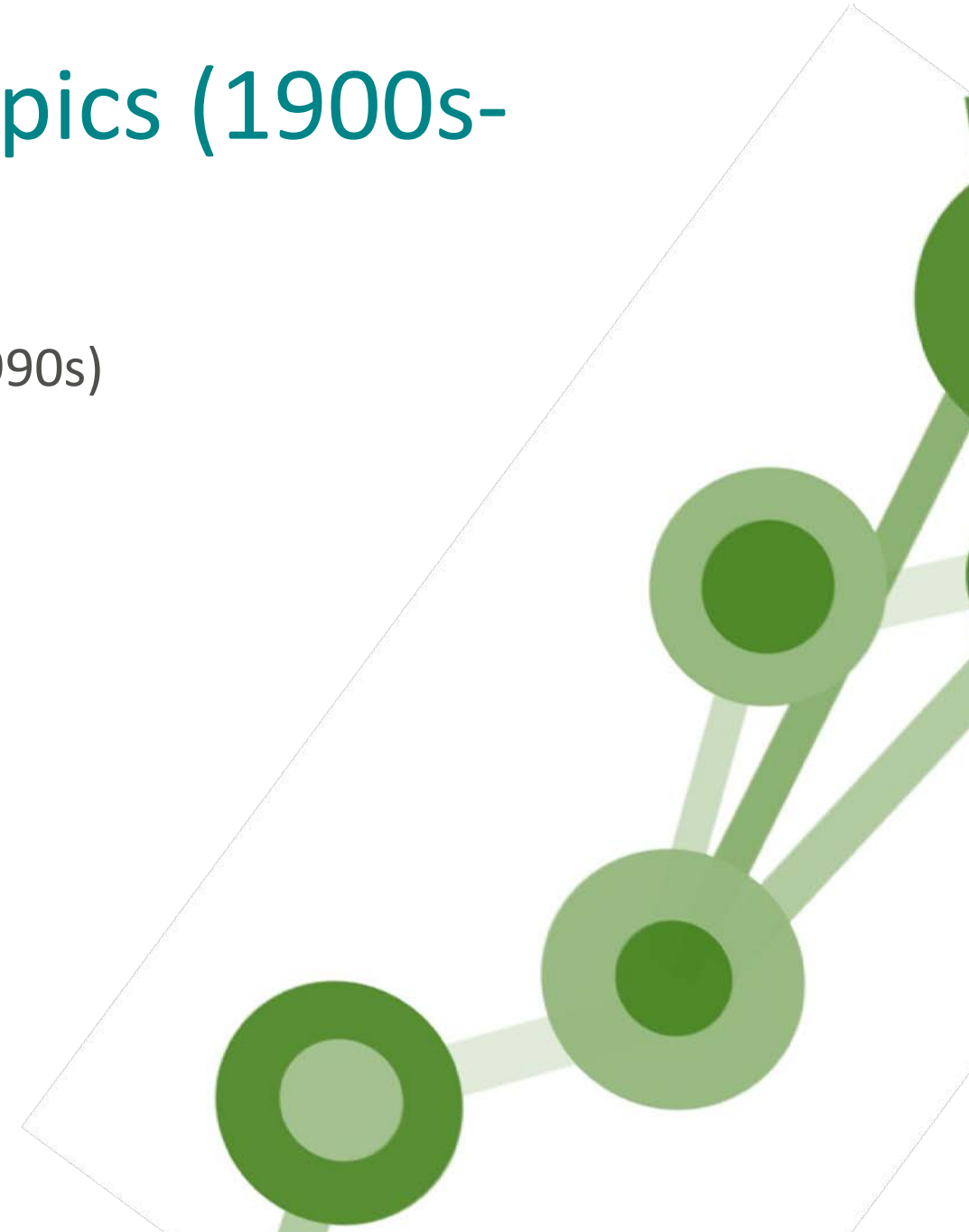
”Study of flows of materials and energy in industrial and consumer activities, the effects of these flows on the environment, and the influences of economic, political, regulatory, and societal factors on the flow, use and transformation of resources”

(Allenby and Richards, 1994)



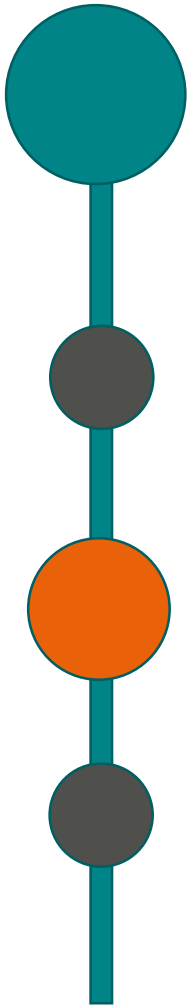
Co-emergence of similar topics (1900s-1990s)

- Co-emergence in different areas (early 1900s-1990s)
- North America
  - Industrial Ecology/Symbiosis/Metabolism/Ecosystems
- Eastern Europe/(Former Soviet Union)
  - Combined Production (kombinirovanaia produksia)
  - Waste-Free Production (bezotkhodnoyi tekhnologii)
- Asia
  - Circular-Based Resource Use



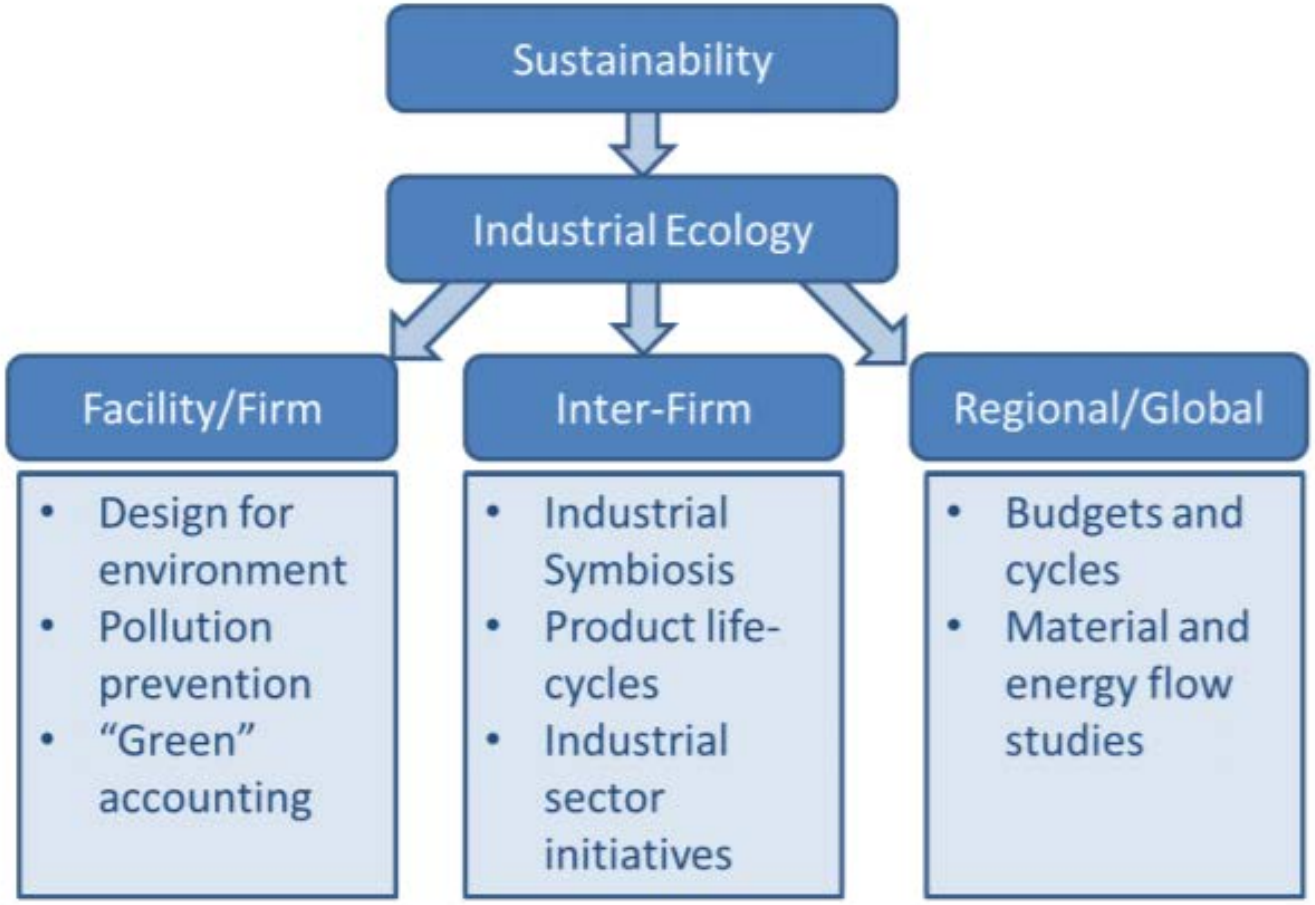
Timeline

- 1800’s collaborative approaches among industries utlizing waste and residual streams
- 1947 (earliest) ”Industrial Symbiosis” used in literature
- 1960s-70s Former Soviet Concepts of IS
- 1970s Kalunborg symbiotic activities begin
- 1989 Frosch and Gallopolous definition of ”industrial ecology”
- 1990 Eco-industrial Park term coined
- 1990s-2000s….exponential ”uncovering” of IS networks and research into their development
- 2000s , CE…



Collaborative (Inter-Firm) Approaches

- IE has different focuses
- Within Facility
- Between Firms
- And Regional/Global Studies
- Industrial Symbiosis (Inter-firm)



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Evolving concept and Research Area

- Traditionally only industrial
- Recently identified value of urban systems-***Urban Symbiosis***
  - Residual Urban Streams
  - Heating/Cooling Networks
- Knowledge and Innovation Synergies
- Capacity Building/Regional Development
- Requires both social and technical expertise to ensure synergies

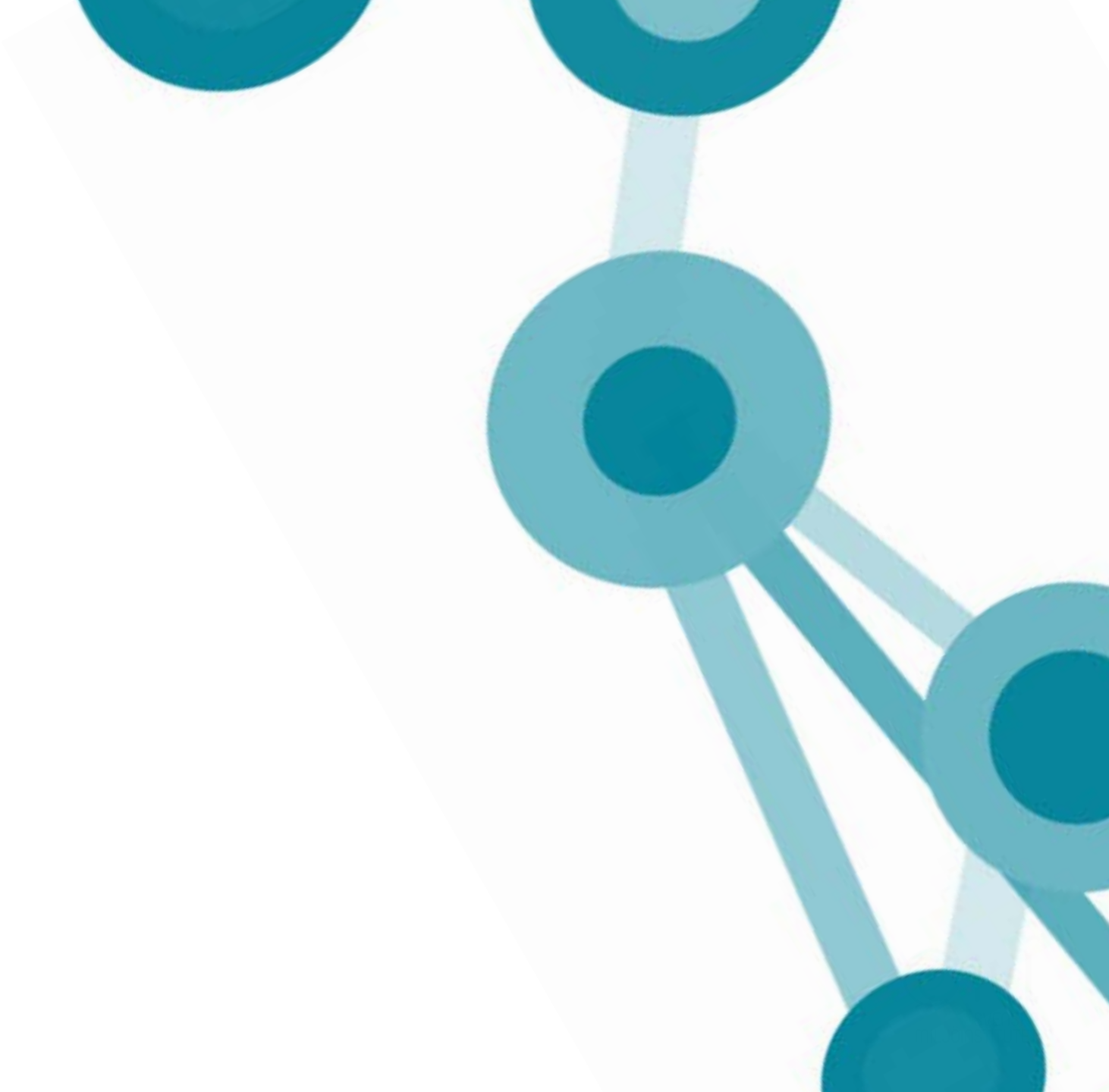
Value of Industrial Symbiosis

- Primary examples outlined in EU CE policy
- Increase value/revenue for residual resources (material, water, energy, etc.)
- Create and develop innovative products and business models
- Improve environmental and economic performance (”win-win” situations)
- Go beyond core business and….**see what your neighbors are doing and what they have**
  - **Energy, Materials, Knowledge**
- Strengthen regional identity and couple to urban systems

1+1=3?

Next Session

- Development of Networks
- Important Insights
- Challenges
- Opportunities



References

Sathre, R., Grdzelishvili, I. (2006) Industrial symbiosis in the former Soviet Union. Progress in Industrial Ecology – An International Journal, Vol. 3, No. 4.

Chertow, M.R. (2000) Industrial symbiosis: Literature and taxonomy. Annual Review of Energy and the Environment 25: 313-337.

Martin, M. (2019) Industrial symbiosis networks: Application of circular economy for resource efficiency. Handbook of the Circular Economy edited by Brandão M, Lazarevic D, Finnveden G., forthcoming 2020, Edward Elgar Publishing Ltd., UK.

Erkman, S. (1997) "Industrial ecology: an historical view." *Journal of cleaner production* 5.1-2 (1997): 1-10.

Industrial Symbiosis Network: Divergence of Applications

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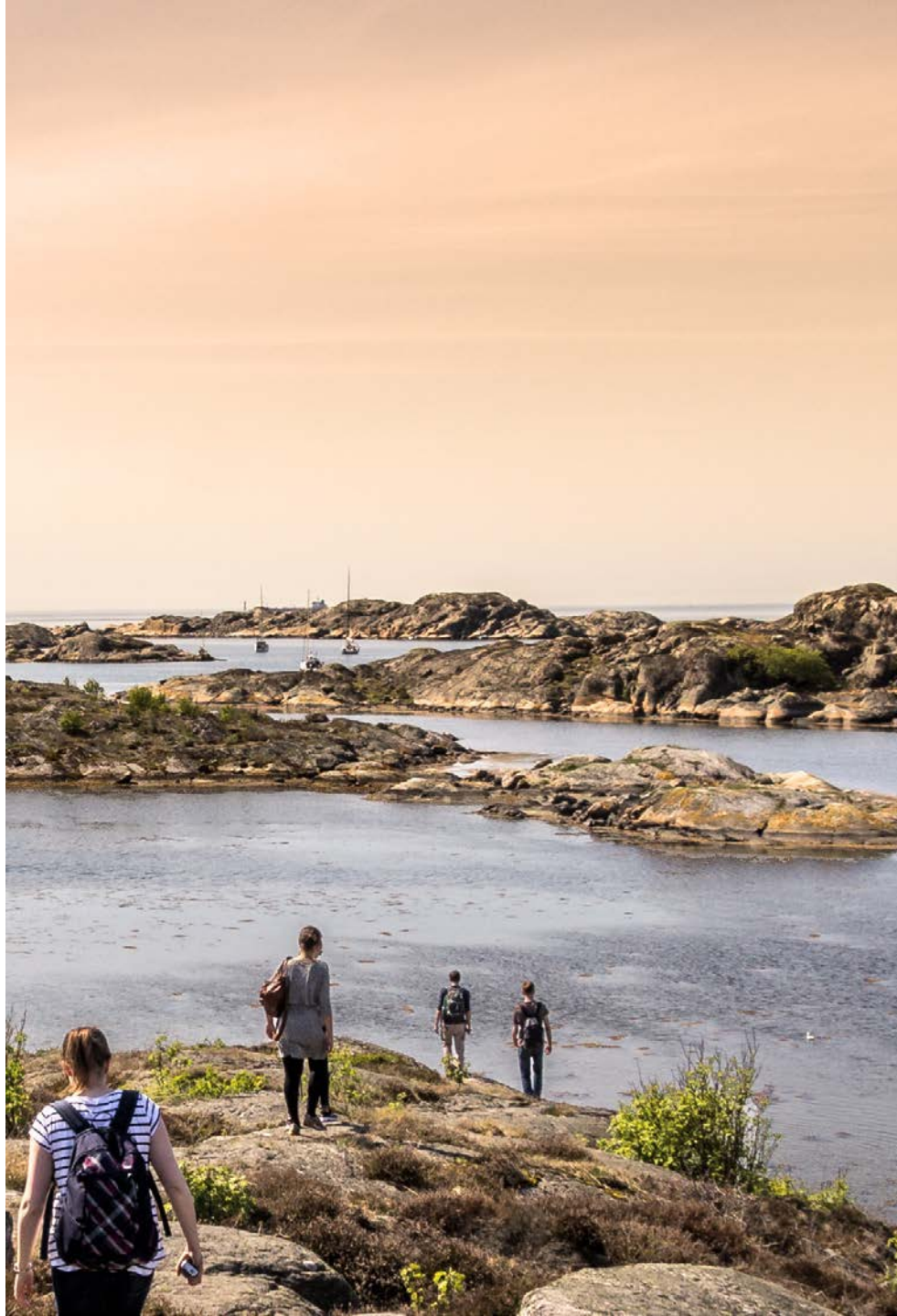
Agenda

- Synergies
- Developing IS Networks: Different Approaches
  - Anchoring, Brownfield, Eco-Industrial Parks, Digitilized
- Barriers and Challenges
- Important Insights
- Embeddedness
- Facilitation, Trust and Social Platforms
- Recap



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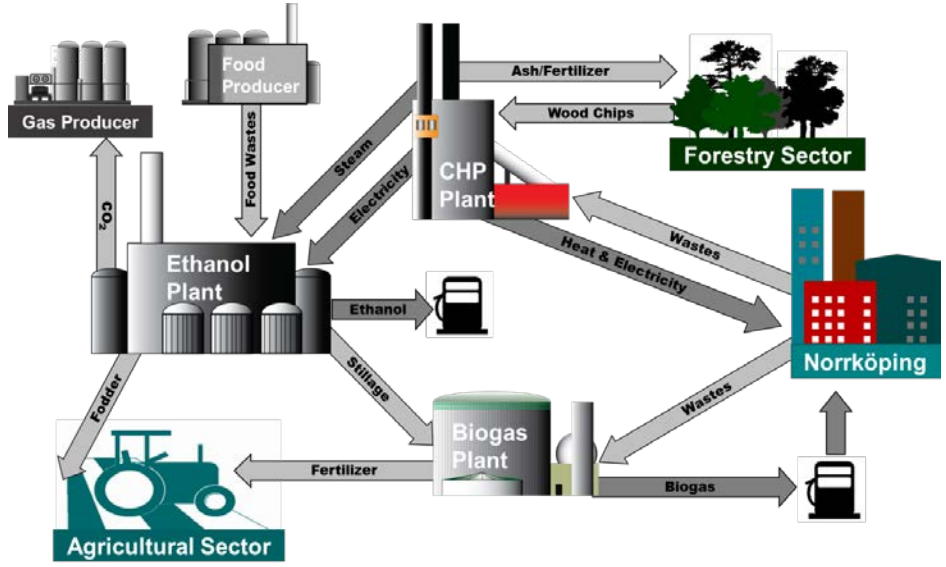

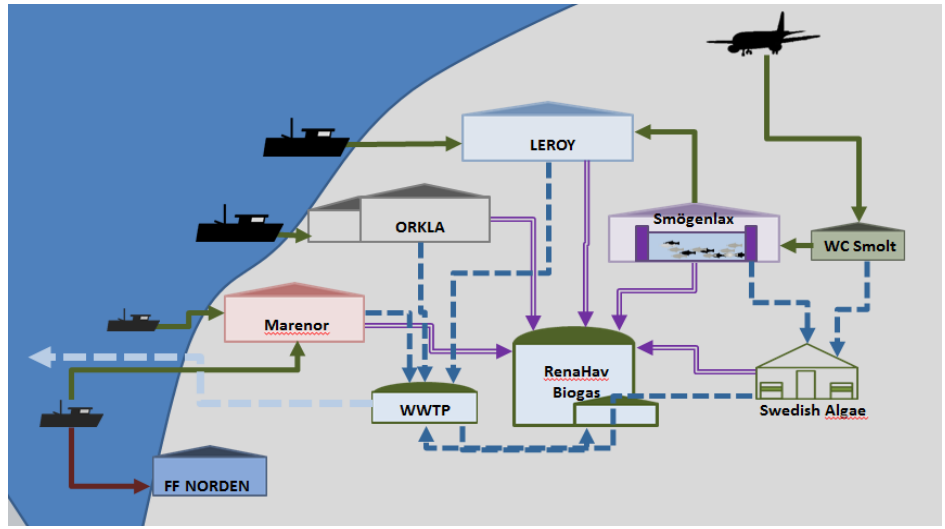

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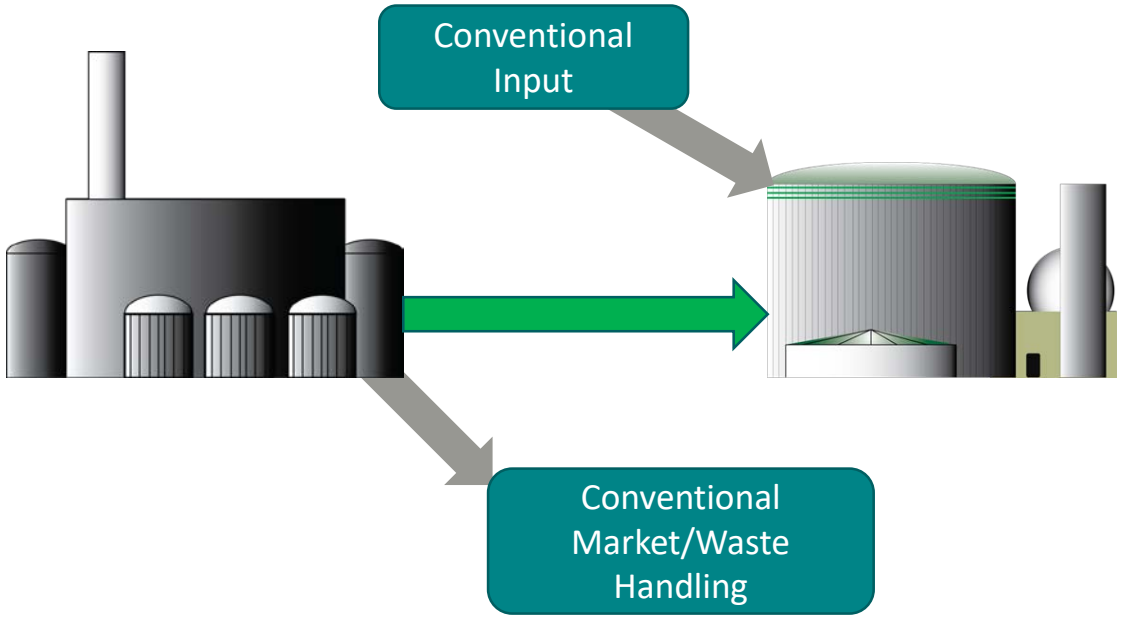
Synergies

- Not only an ”exchange”
- Requires extensive development
  - Technical Feasibility
  - Viability
- Business Models/Contractual Agreements
- New Processes
- Changed raw material streams

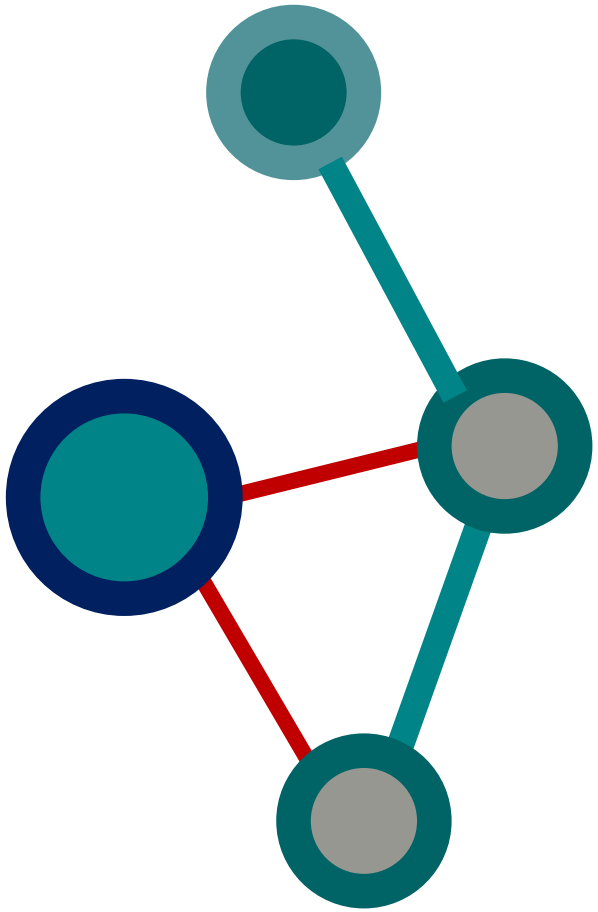


Anchoring/Upcycling

- Based on an existing system/actor
- Typically energy (CHP)
- Important outputs
- Many come to take advantage of the proximity
- Developing/Planned industry (not there yet)
- Upcycling of residual materials to add value

Organic Development

- Most common form of IS Networks in those uncovered
- Develop over time
- Often an ”anchoring involved” but the system grows successively
- New businesses come in, other create new synergies
- New technology/innovation
- Examples: Kalundborg



Brownfield Development

- Start from planning stage
- Regional development plan
- Identify potential actors
- Match inputs-outputs
- Popular option in e.g. China

- Often failed to take shape and be realized in e.g. Europe and USA

Brownfield: Gotland Industrial Symbiosis Network

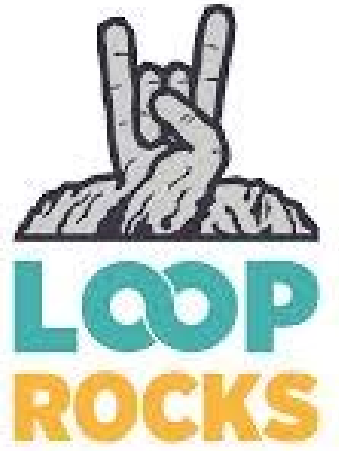
- Fossil-Free Island
- Circular Economy Frontrunner
- Potential
  - Location
  - Companies
  - Complementary Competences
  - Future Direction
- Stay tuned…

A step further: Eco-Industrial Park

- Typically several ”clusters” of industries
- Bounded spatially
- Contains industrial symbiotic network
- But, design of the park with the surrounding environment in mind

For the tech-savy: Digitally Mediated Symbiotic Exchanges

- Matching of
  - Needs
  - Residual streams
- Cross regional cooperation
- ’Dating sites’ for firms
- One-off exchanges, or continued streams
- Rely on financial support/fees



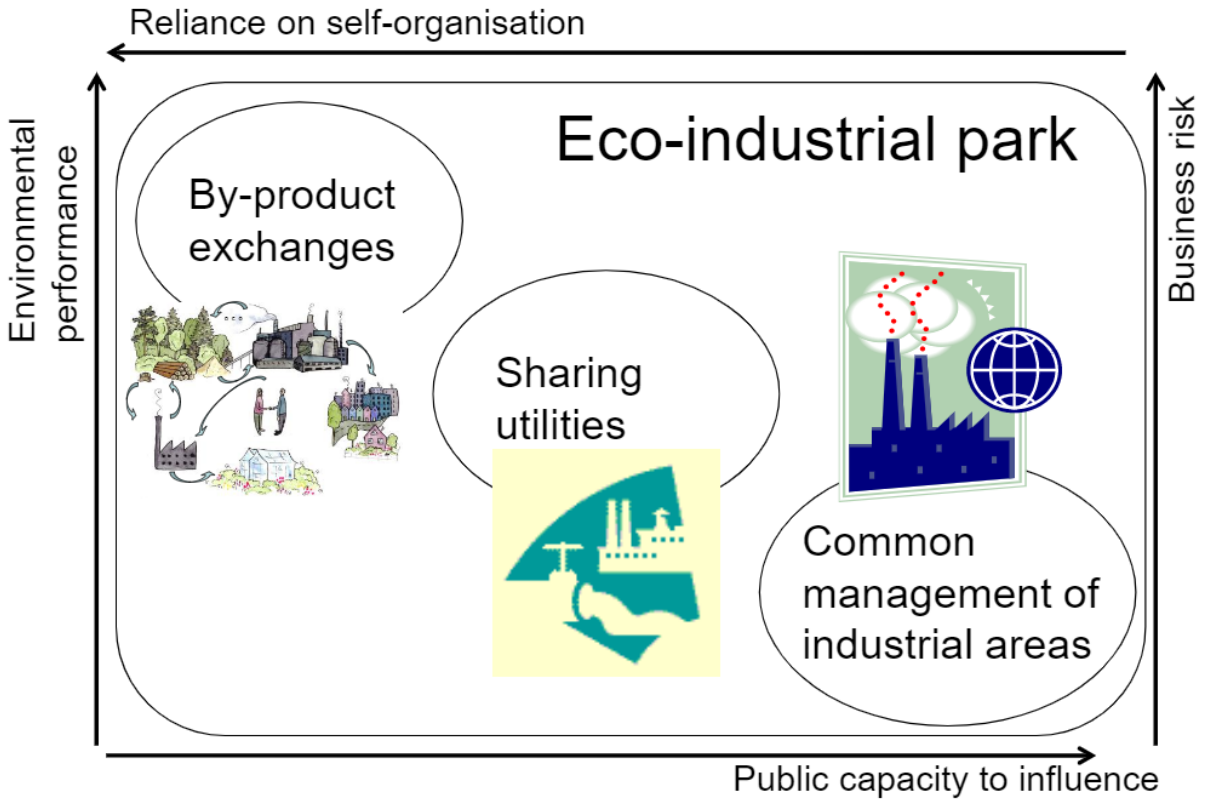
Are there any barriers?

Barriers

- Investments in new technology
- Contractual Agreements
- Technical Lock-Ins/Flexibility
- Regulatory Barriers (Waste Regulations)
- Need of facilitation
- Data

Different Approaches, Different Benefits and Risks

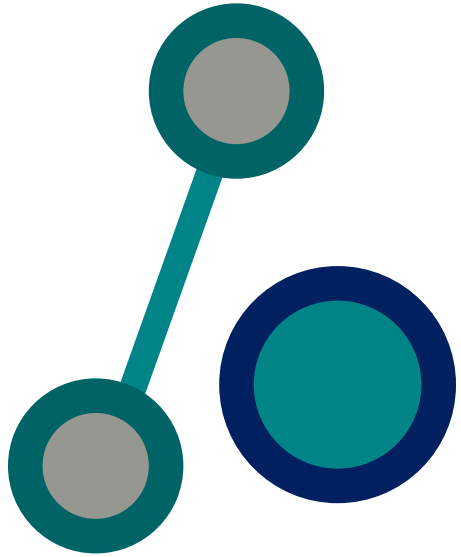
- Different levels of risk as the complexity increases
- Easier to instigate single by-product/utility exchanges
- Sharing of utilities may require infrastructural development
- Management of entire areas requires consensus and organization



Based on Eklund (2018) and Van Berkel (2008)

Embeddedness

- *Degree of embeddedness determines the scope of the cooperation process and the ability of the network to achieve the potential benefits of IS.* (Domenech, 2010)
- Positive impact on the value associated with synergies/exchanges
- Main components of this embeddedness for relations
  - Trust
  - Fine-grained information transfer
  - Joint problem solving
  - Multiplexity

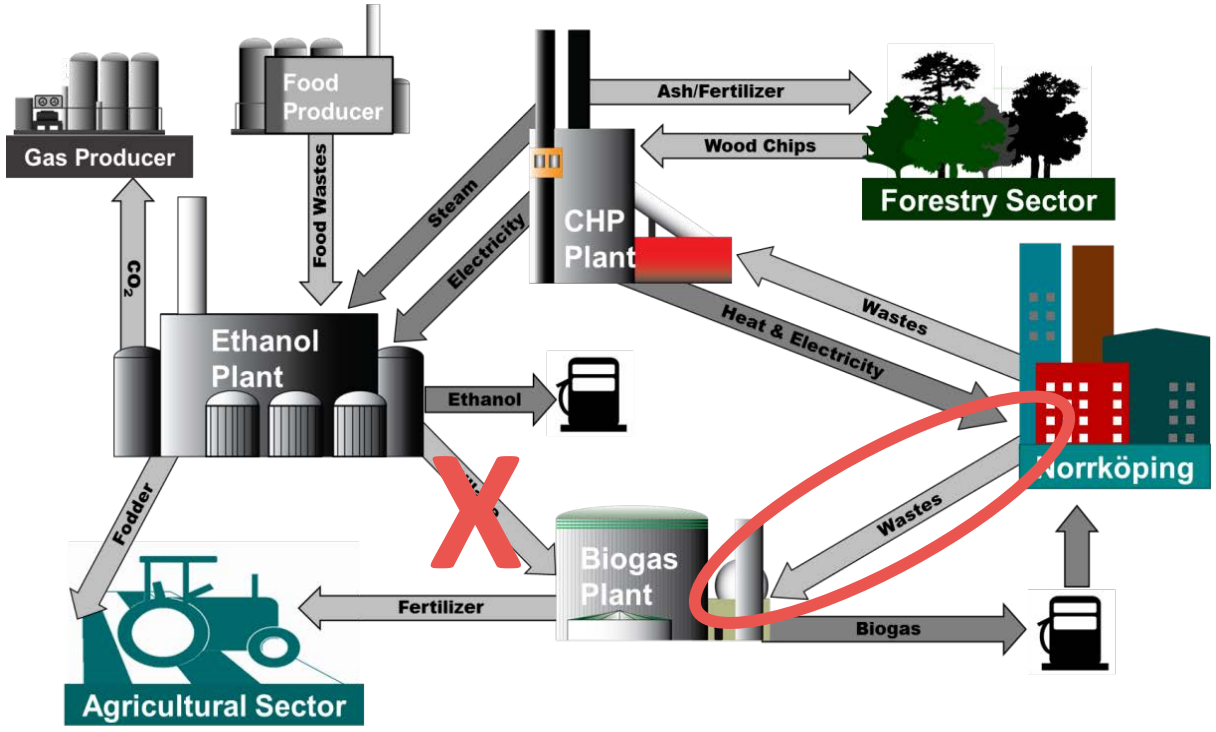


Facilitation

- Important start IS network development
- Ensures time, support and space for its development
- Important in many contexts
- Facilitator
  - Typically an older gentleman
  - Has worked with the industry(ies)
  - Large regional networks
  - Can ”speak their language”
  - Builds trust and legitimacy

Flexibility is important

- Many IS networks have changed over time
- Organic Development
- Companies come and go
- Flexible with inputs
- Important to ensure contractual agreements are met



Trust and Cooperation

- **<u>Majority of research points to trust being important for IS success</u>**
- Developing new synergies takes time
- Must engage all parties and develop relationships
- Communication is also a key component
- Risks: Example from Östergötland region in Sweden (Urban Industrial Symbiosis)

Ensure collaboration and social platforms

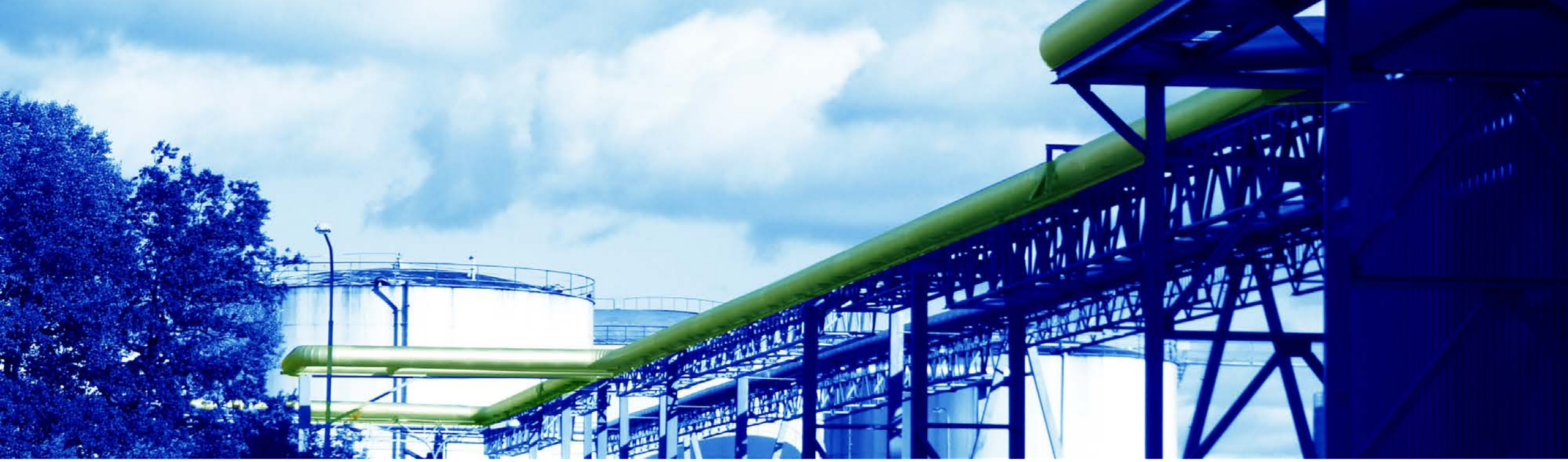
- Create Social Platforms
  - Workshops
  - Discussions
  - ”After work” events
- Involve different stakeholders in region and firms
- Requires knowledge and acceptance on different levels
  - CEO, Engineers, Sales, Sustainability, Economy
  - Regional Government
  - Research and Society

EU CE

- IS as a working/practical example of CE I Circular Economy Package (European Commission):
  - “As a way to increase circularity in production processes”,
  - “As a key theme of the innovation, investment and horizontal measures, through expanding the base of knowledge in H2020 projects and as part of R&I investment for cohesion funds and policies”
- Revised policy document (Article 5, Waste Framework Directive) which promotes IS:
  - *“a substance or object resulting from a production process the primary aim of which is not the production of that substance or object is considered not to be waste, but to be a by-product.”*

What's needed?

- Explore opportunities outside traditional supply
  - Explore unrelated firms and neighbors
- Waste minimization and resuse may not be optimal
  - Developing new valorized products and materials
- Regulatory Environment Determines what is possible
  - Voluntary agreements and flexible regulations can aid IS development
- Social context is as important as technical feasibility
  - Create culture for collaboration, not only ”waste transactions”
- Information on the benefits of IS (firms, network, region)
  - Economic, Environmental, Socio-economic



Role of Industrial Symbiosis for Environmental Impact Reduction and Regional Development

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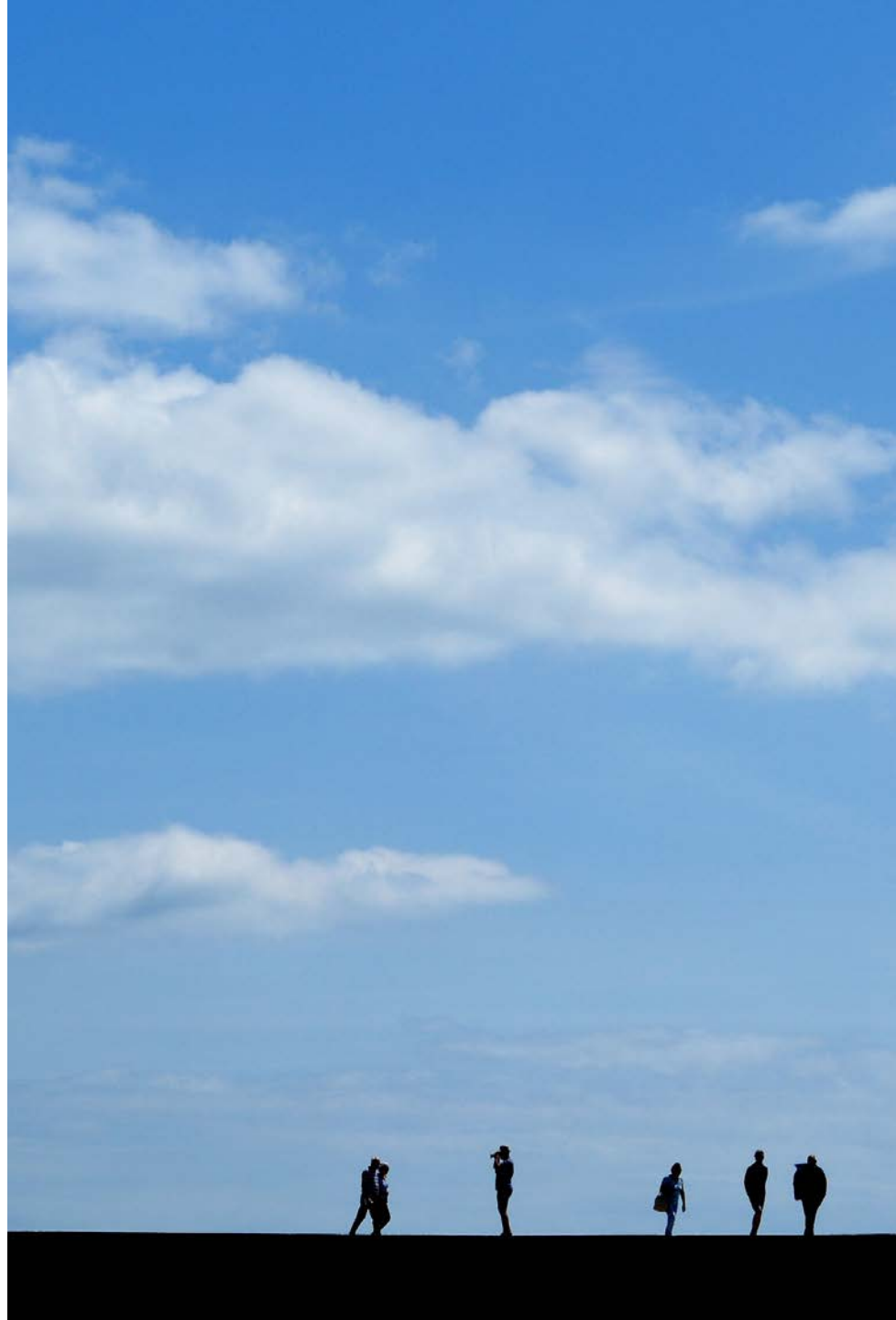
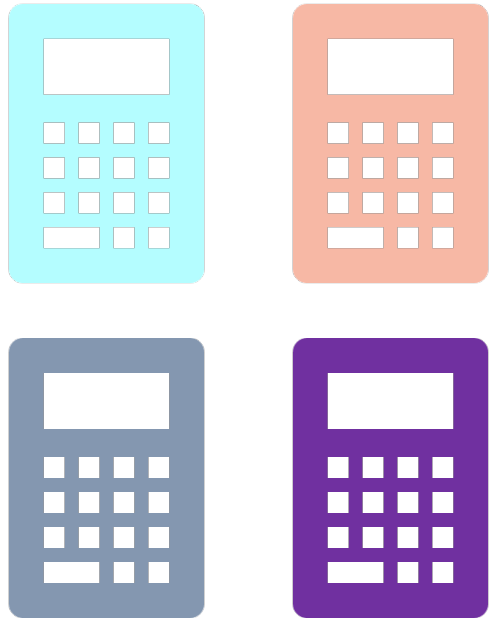
Agenda

- Applying System Analysis to IS Networks
- Examples from my research:
  - Åby IS Network
  - Sotenäs Symbiotic Network
  - Beer: Nya Carnegie and Grönska (Stockholm)
- Final Thoughts



What gets measured, gets managed…(?)

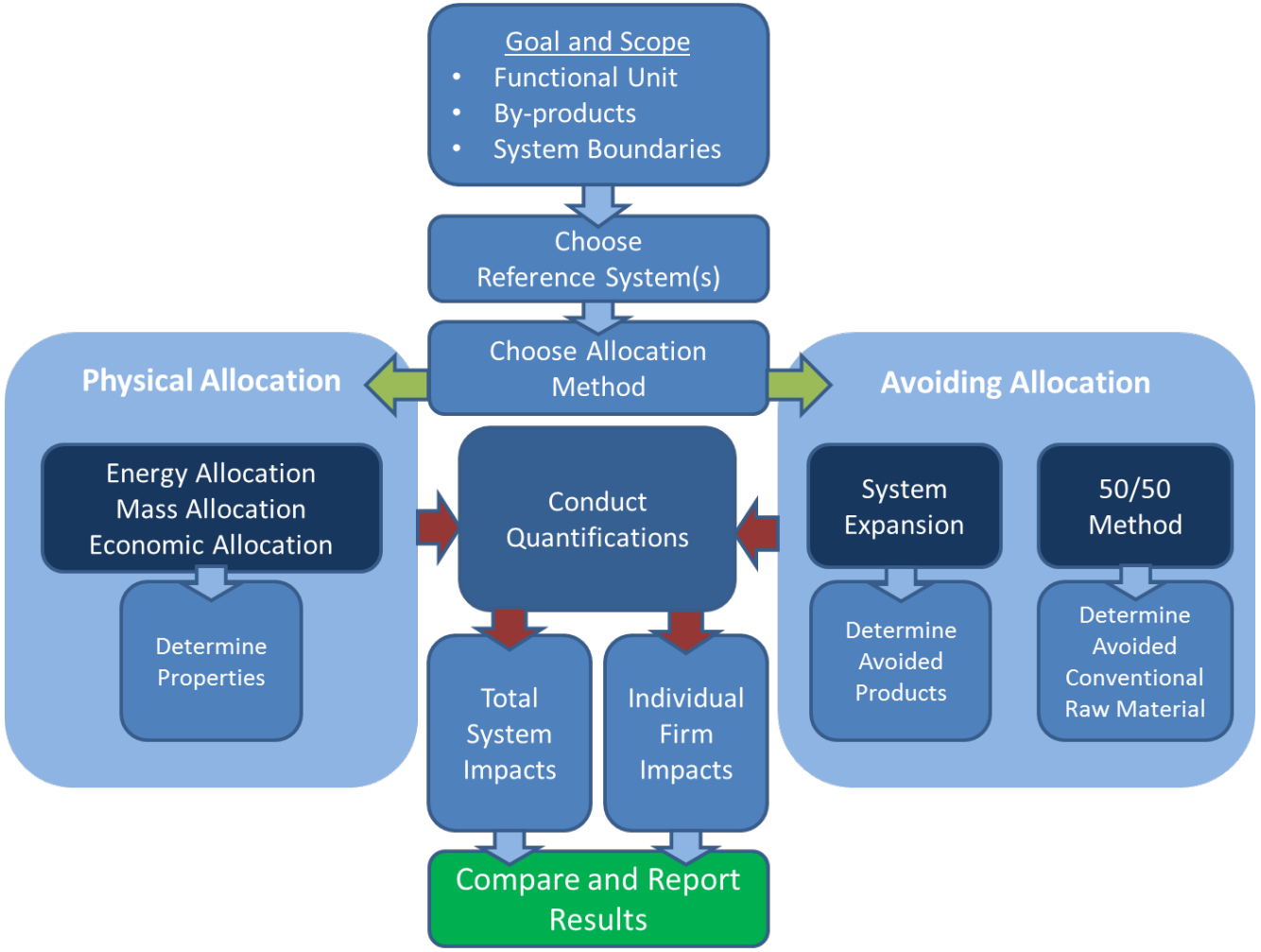
- Industrial symbiosis often assumed to entail large benefits, but few studies reviewing these benefits
- Important to portray the potential
- Aid in facilitation
- Showing value for the network
- Benefits for firms involved



Systems Analysis: Review Performance and Potential

- Industrial Ecology based tools
  - LCA
  - MFA
  - Life Cycle Sustainability Assessments (Economic, Environmental and Social impacts)
- Socio-economic indicators
- Energy Systems Analysis
- Social Dynamics & Instutional Capacity Building
- Organizational Theory
- Data/IOT

Applying LCA to IS Networks



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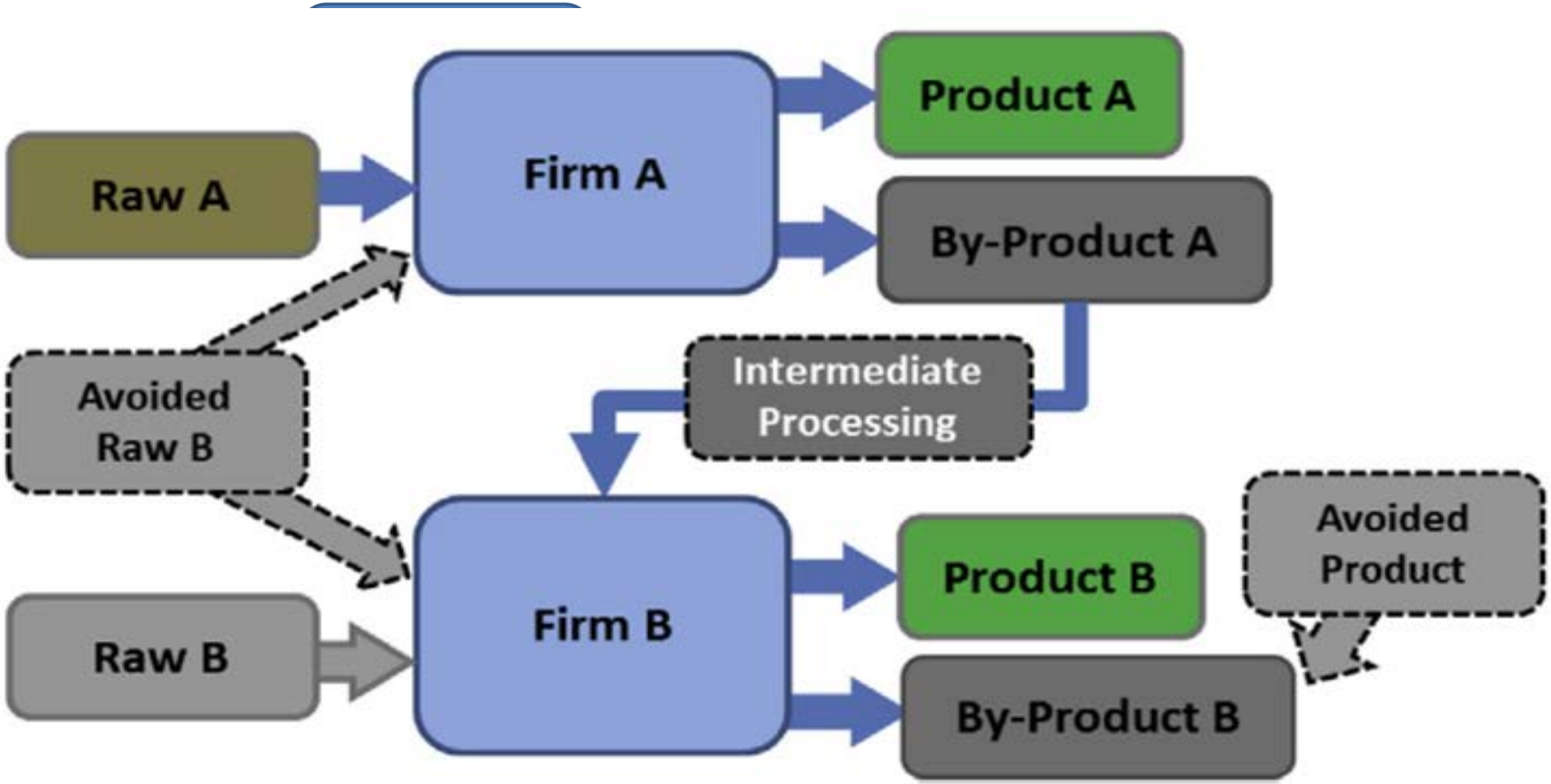
Applying LCA to IS Networks



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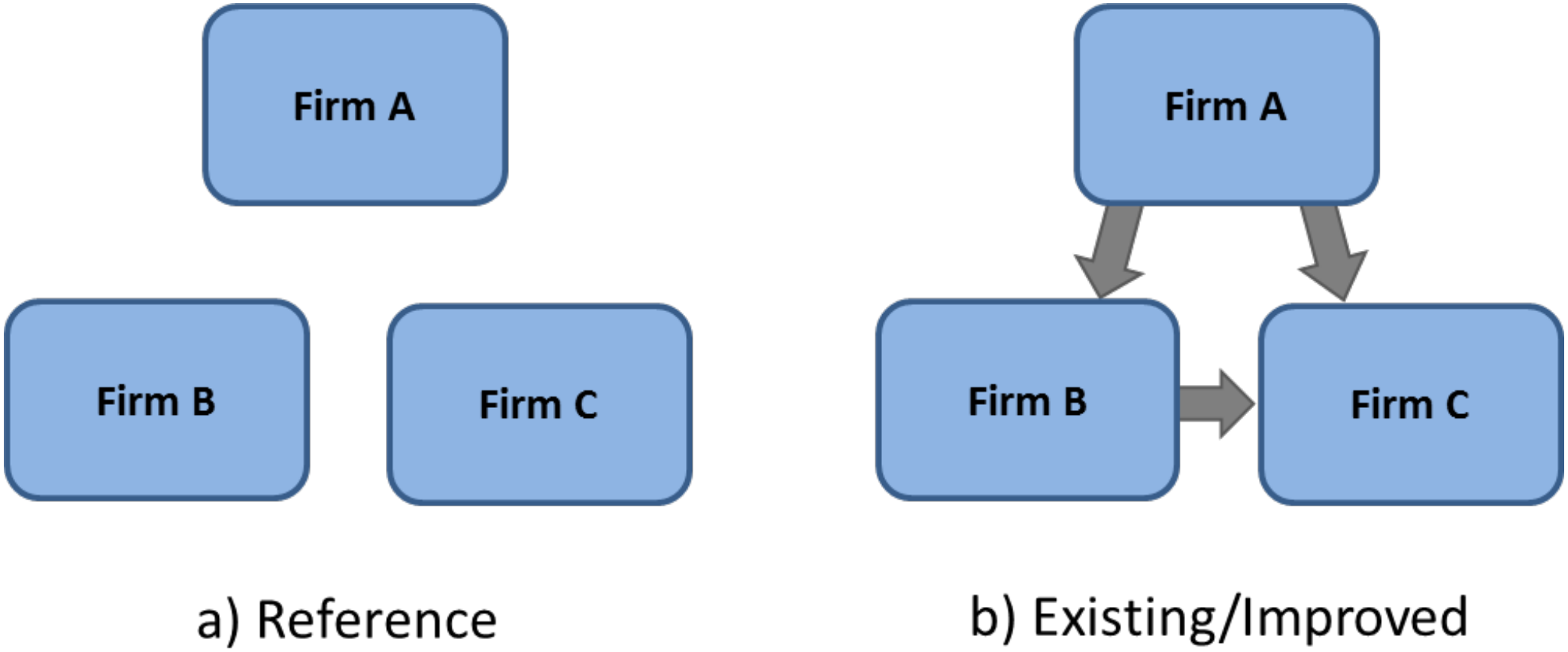
Applying LCA to IS Networks



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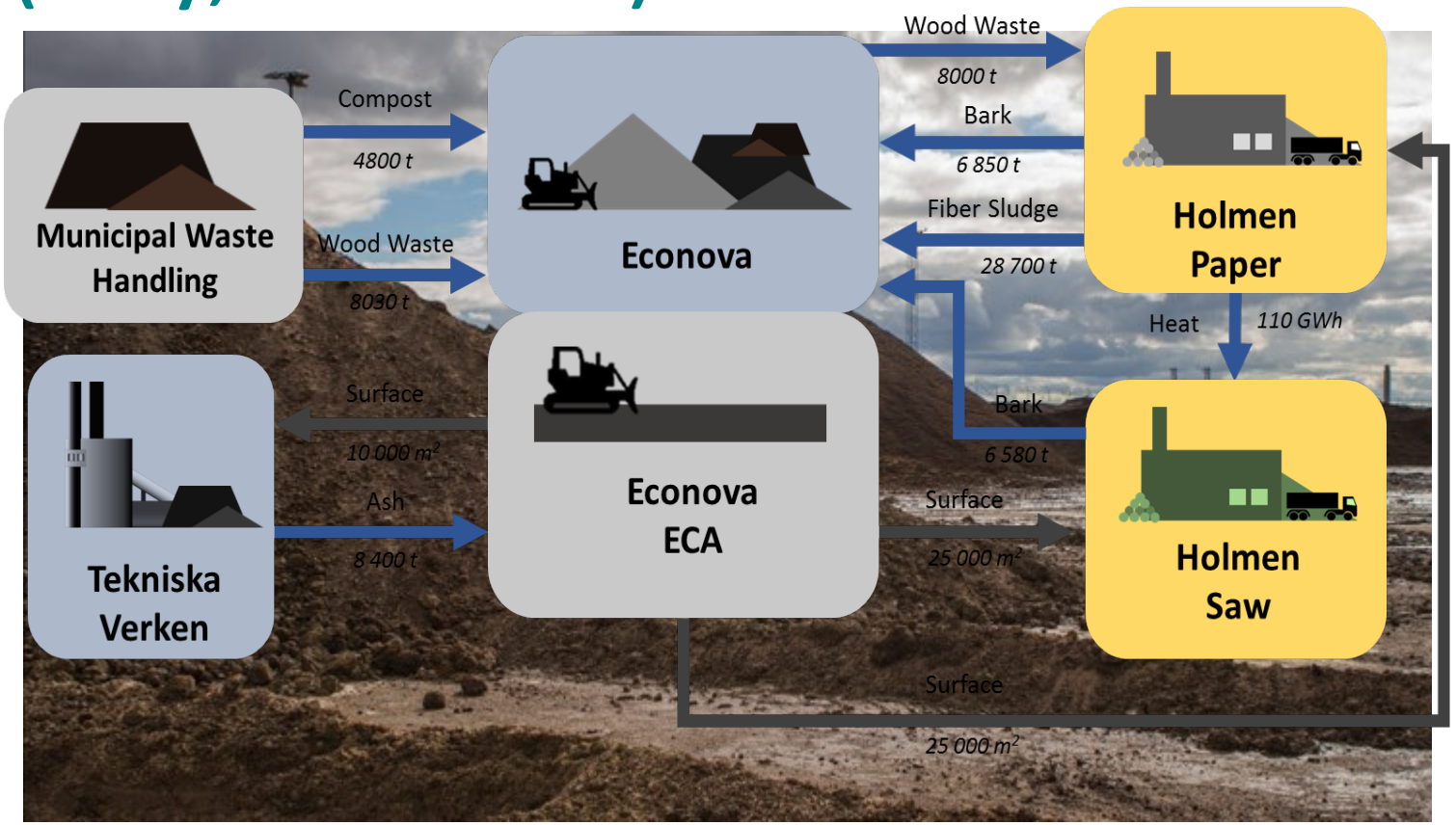
Examples

The IS Network (Åby, Sweden)

- Important Members:
  - Econova (Soil, Surfaces)
  - Holmen Paper (Paper)
  - Holmen Saw (Boards)
  - Tekniska Verken (Heat, Elec.)
- Many of exchanges *facilitated* by Econova
- Replacement of Peat
  - Fiber Sludge→ Fiber Mulch
  - Bark→Bark Mulch
- Ash used for surfaces (ECA)
  - **E**conova **C**ement Stabilized **A**sh (and rock)
- Heat Exchange from Forest



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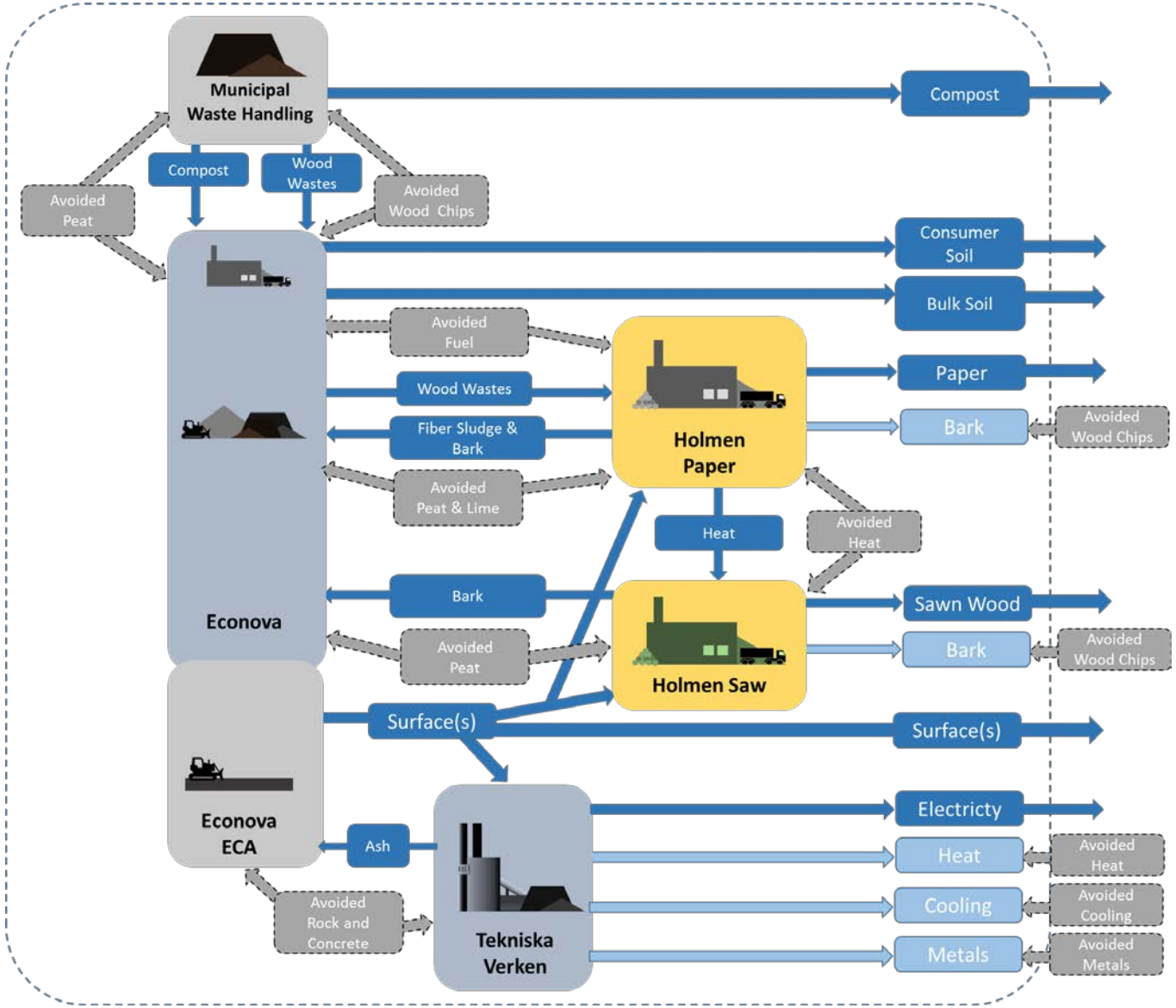
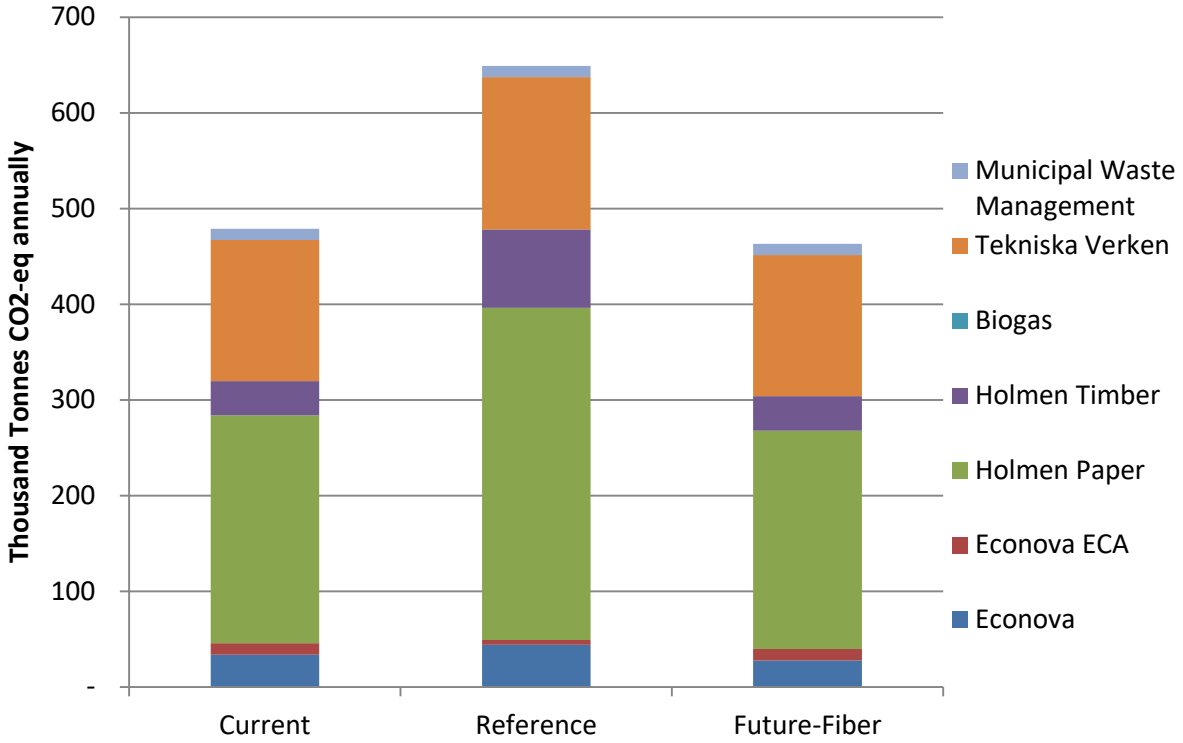
System Boundaries

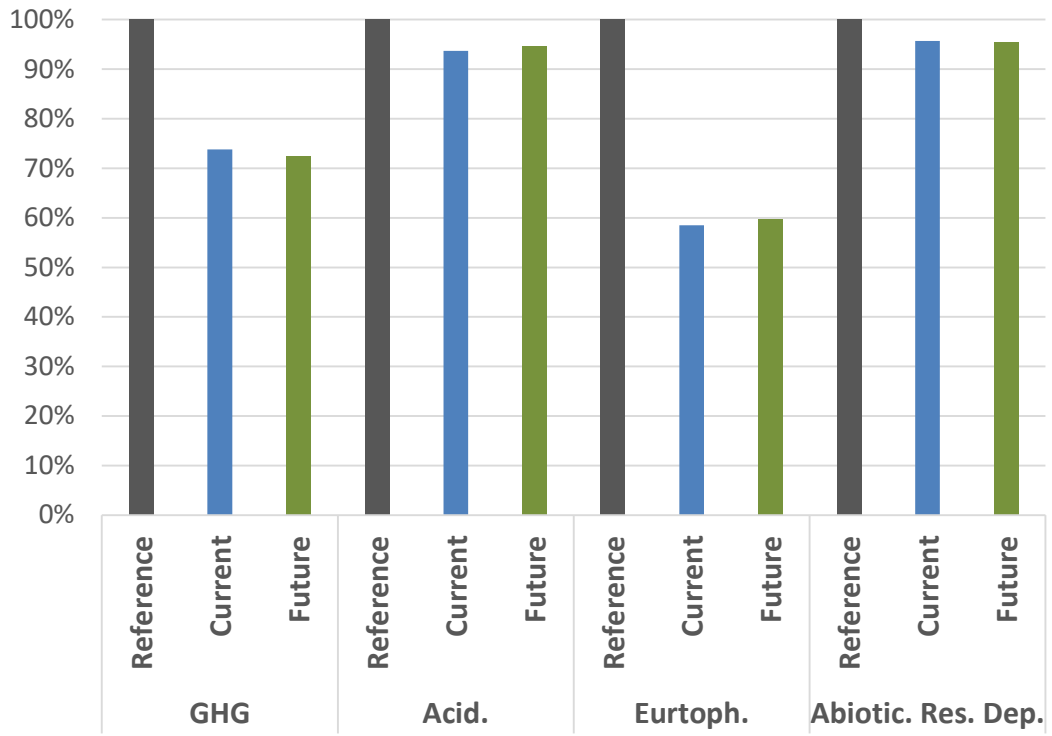
- Compared to Reference Scenario (of similar outputs)
- Figure shows exchanges and avoided Conv. Materials/Energy
- *Not shown:* Conv. Raw Material Input Burdens
- Functional Unit(s) in blue leaving boundary
- By-Products leaving in light blue (and associated avoided products)



Martin, M., Svensson, N. Eklund, M. (2015). Who gets the benefits? An Approach to Assess the Environmental Performance of Industrial Symbiosis. Journal of Cleaner Production 98(1), 263-271.

Results: Performance and Potential





- Reduction of 170 000 tonnes CO_2-eq emissions annually
- Eutrophication impact reduction 750 tonnes PO_4-eq annually
- Acidification impacts of reduction190 tonnes SO_2-eq annually
- Abiotic resource depletion reduction with nearly 340 000 GJ-eq annually

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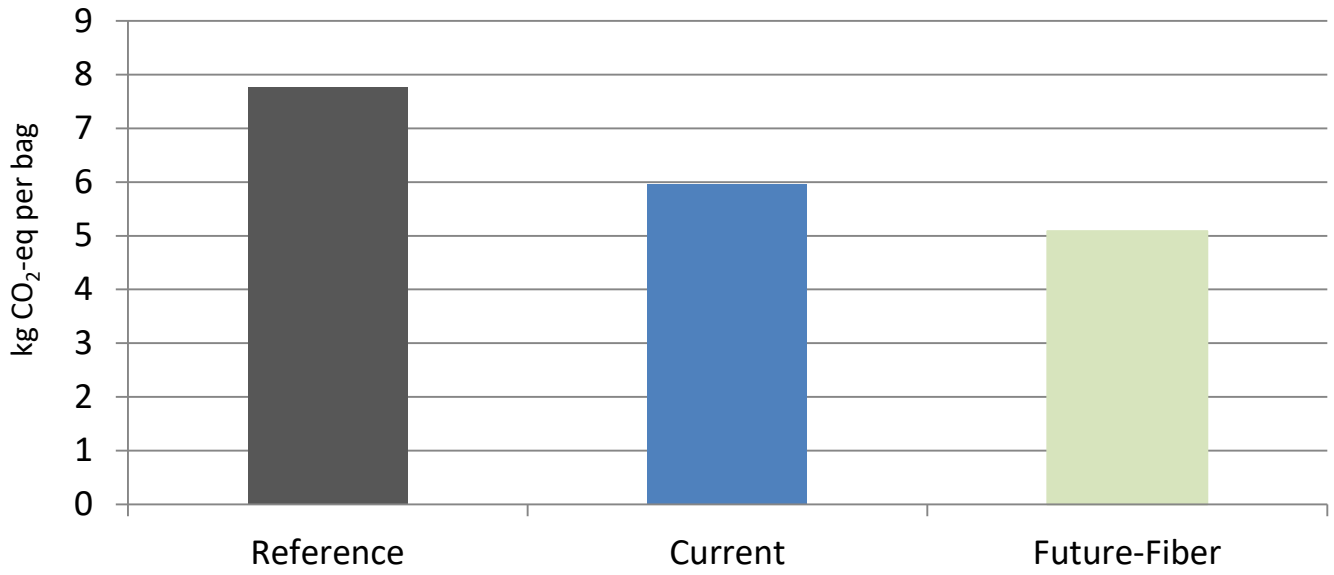
Implications for Product (Soil Bags)



- Significant GHG emissions possible for product
- 24% reduction GHG emissions (Current vs. Ref)
- 34 % reduction if including larger share of Fiber Mulch
- Both bulk soil and gardening soil (bags) benefit

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For Åby, IS has led to…

- Large potential for IS network to contribute regional environmental impact reductions
- Benefits for main products of the system
- Large future potential by reducing more peat
- ECA Surfaces replacing concrete and asphalt surfaces
- Facilitation efforts for IS Network are important to highlight
- Selection of counterfactual reference scenario is important/sensitive

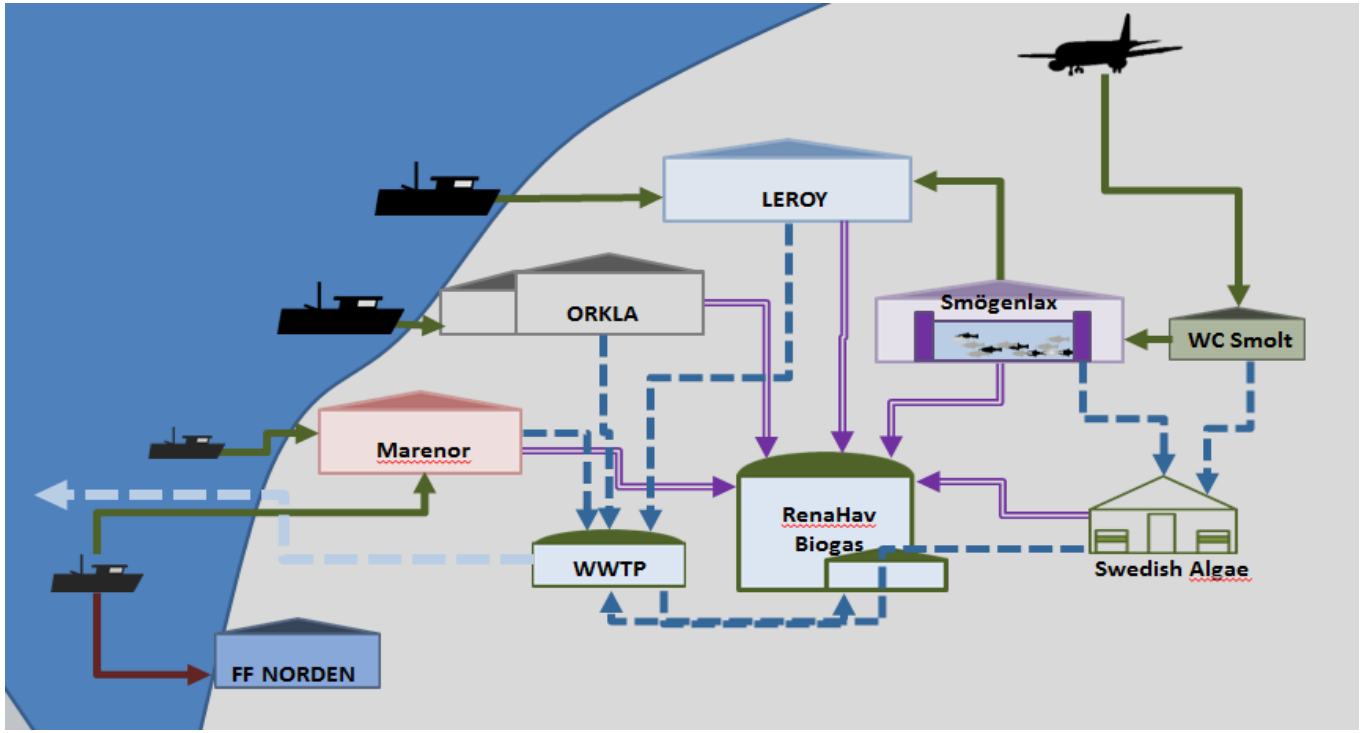
See article (in review) and report:

-Martin, M. (revised, in review). Evaluating the environmental performance of facilitated synergies for producing soil and surfaces through industrial symbiosis. Submitted to Journal of Industrial Ecology.

-Martin, M. (2018) Assessing the Environmental Implications of a Regional Industrial Symbiosis Network for Innovative Products. IVL Research Report C297.

Sotenäs Industrial Symbiosis Network

- Sea-Food Producers
- Aquaculture (Land-Based Salmon Farming)
- Biogas Plant
- Algae Production
- Sea Litter Removal/Recycling
- Waste Water Treatment Plant (WWTP)



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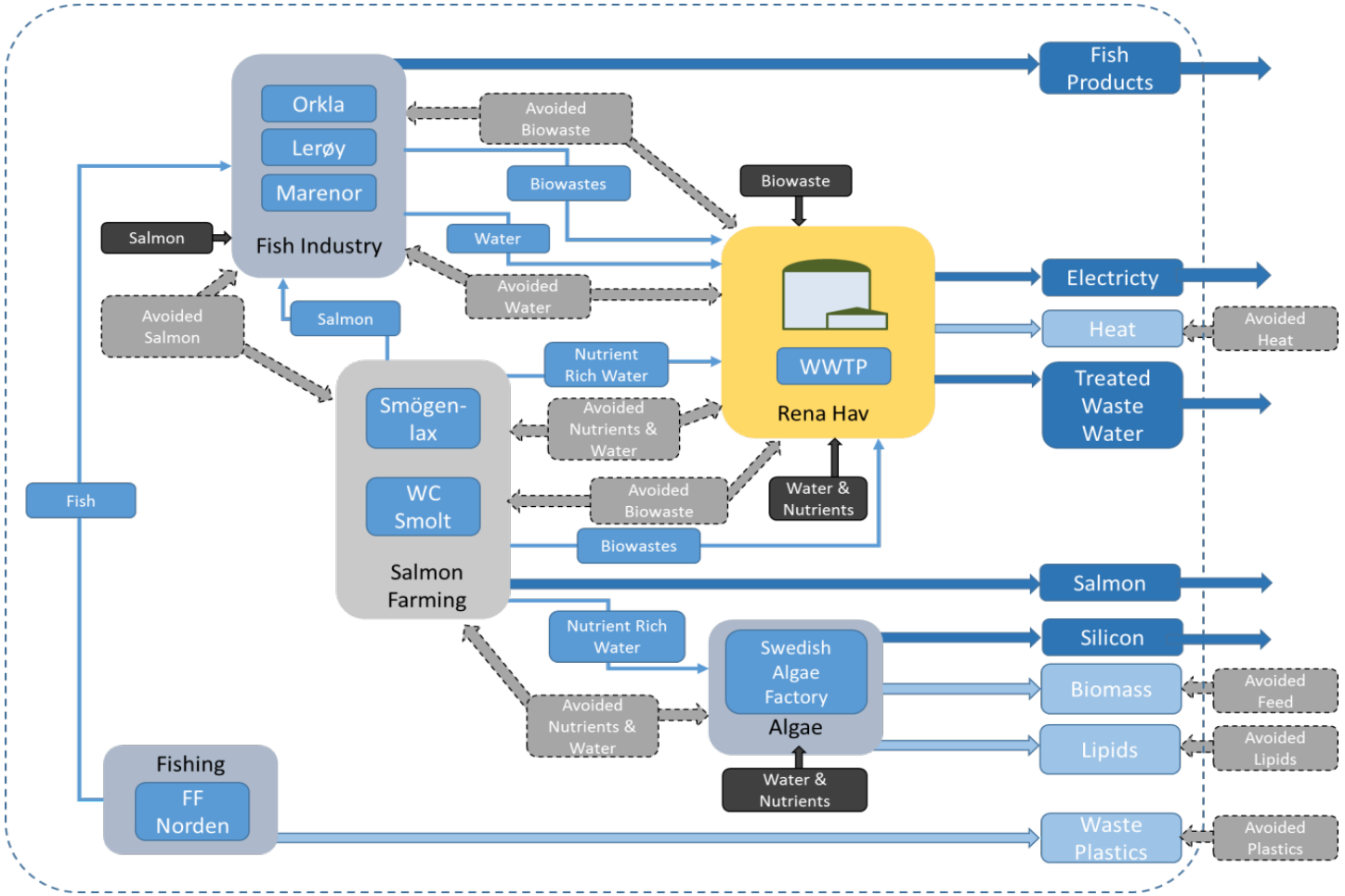
Environmental Implications

- Reference Case (No Symbiosis)
- Functional IS Network (Developed)
- Large number of products
- By-Products leaving the system avoid

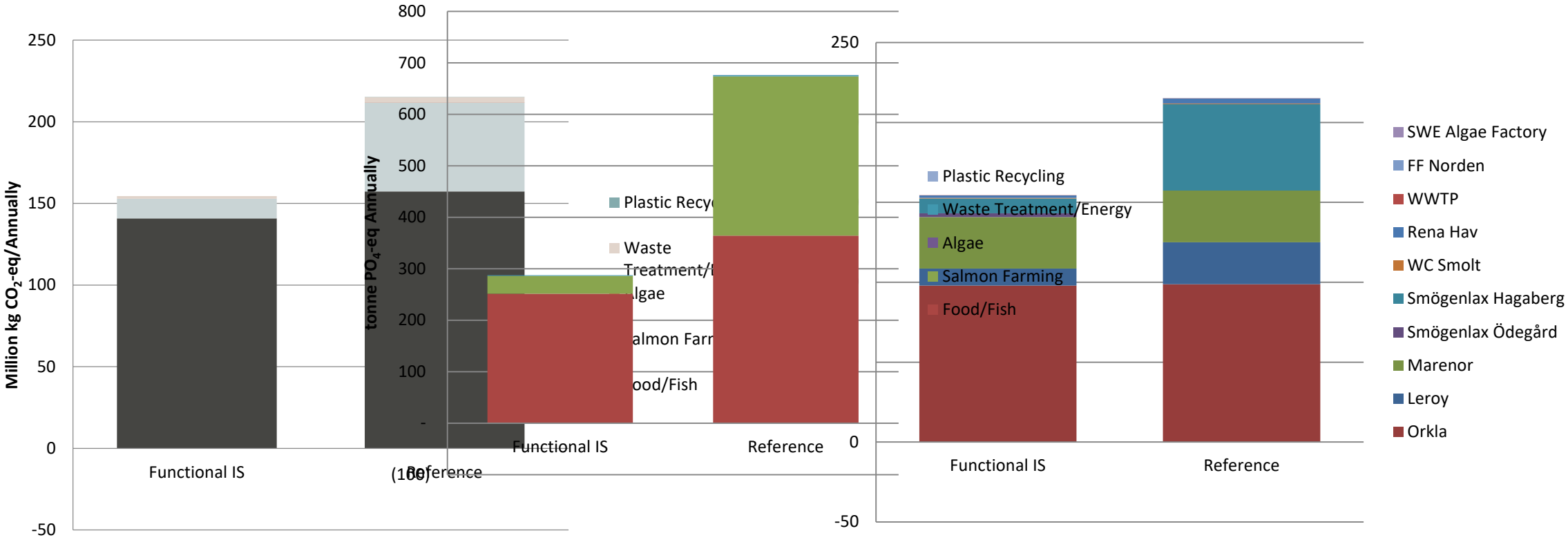


Martin, M. and Harris, S. (2018). Prospecting the sustainability implications of an emerging industrial symbiosis network. Resources, Conservation & Recycling 138, pages 246–256.

Socio-Economic Implications

Social	Economic
1. Job retention and creation from synergy project implementation and operation.	1. Economic viability of the project, and will the economy of the community be improved?
2. Improvement and strengthening of the local skills basis.	2. Impact on costs for vital process inputs (including energy, water and materials).
3. Impact on R&D and local innovation.	3. Impact on sales values as a result of on-selling of by-products.
4. Regional identity/ pride /sense of value.	4. Impact on operational efficiency and flexibility of individual operations.
5. Community engagement - are engagement processes in place and working effectively?	5. Impact on costs of environmental and other regulatory compliance.
6. Community engagement efforts can benefit from the platforms and processes established for the realization of regional resource synergies.	6. Improvement in medium and long-term security of access to vital business resource (e.g. land, ore, water etc).
	7. Impact on company risk and liability profile as a result of resource synergies.
	8. Benefit from improved relationships with government and external stakeholders.
	9. Impact on net contributions to the local economy as a result of synergy project implementation and operation.

Results-Environmental



- 60 000 tonnes CO_2-eq annually
- 390 tonnes PO4-eq annually
- Reduction of 19 million tonne-km annually

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Results-Socio-Economic

	Current	5 years	10 years
Job retention or creation of the IS network	20	100	180
Number of new companies	5	25	45
Potential revenue of the network (MSEK/year)	~2	400	1 000
Number of visitors due to the network (persons/year)	1 000	2 000	4 000
Number of hotel nights / year	700	1 400	2 800
Spending due to visitors (estimated) (MSEK/year)	2.1	4.1	8.2
Savings on waste disposal transport compared to reference model levels (MSEK/year)	-	164	164
Funding of research and development linked to network (MSEK/år)	6	50	20

For Sotenäs, IS can lead to…

- Large potential for IS network to contribute environmentally and socio-economically
- A reduction of nearly 60 000 tonnes CO_2-eq emissions per year
- Eutrophication impact reductions of 390 tonnes PO_4-eq per year
- Reduction of over 19 million tonne-km per year in transportation of wastes and other products
- Economic contribution of the network would be about 10% of the Sotenäs GDP
- 20 new companies, 100 new or retained jobs
- Double the number of visitors to the symbiosis network
- 164 MSEK in savings on waste disposal transport compared to reference model levels

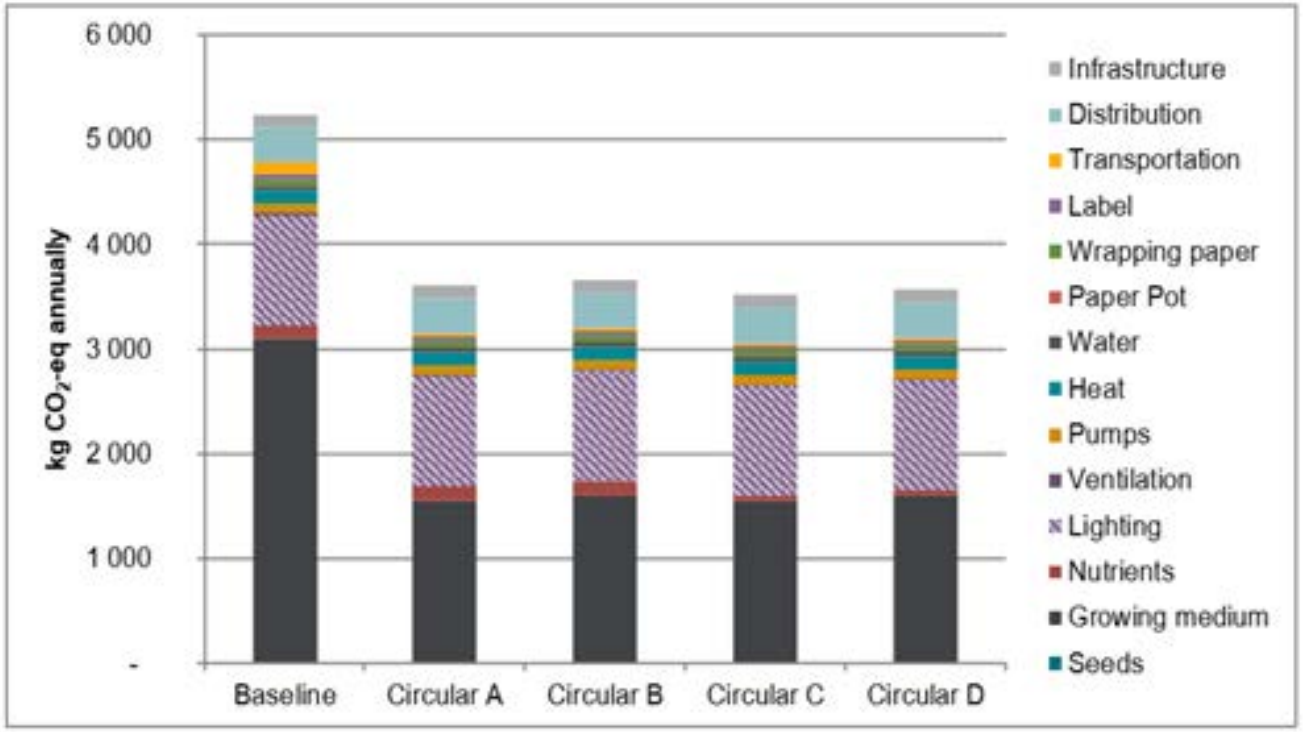
See article and report:

-Martin, M. and Harris, S. (2018). Prospecting the sustainability implications of an emerging industrial symbiosis network. Resources, Conservation & Recycling 138, pages 246–256.


MADE OUT OF PURIFIED SEWAGE WATER
BRYGGERIET
PU:REST
RECYCLED WATER PILSNER

Urban Symbiosis: Urban Vertical Farming

- Employing urban residual streams in urban farming systems
- Urban compost, recycled paper and brewing spent grains as growing medium
- Urban food waste-biogas-biofertilizers
- Large environmental benefits
- Reduced waste handling
- Resilient food systems



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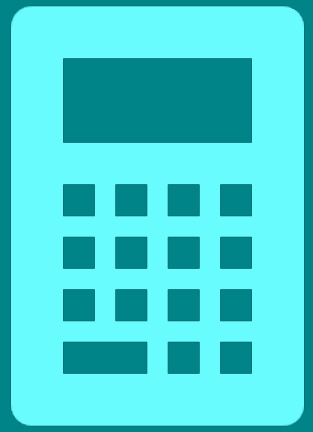
Performance: Only one piece of the puzzle



References

Martin, M. (2019) Evaluating the environmental performance of producing soil and surfaces through industrial symbiosis. Journal of Industrial Ecology. Online, In Press.

Martin, M. (2019) Industrial symbiosis networks: Application of circular economy for resource efficiency. Handbook of the Circular Economy edited by Brandão M, Lazarevic D, Finnveden G., forthcoming 2020, Edward Elgar Publishing Ltd., UK.

Martin, M. and Harris, S. (2018). Prospecting the sustainability implications of an emerging industrial symbiosis network. Resources, Conservation & Recycling 138, pages 246–256.

Martin, M. et al. (2019) Exploring the environmental performance of urban symbiosis for vertical hydroponic farming. Sustainability (In Press).

Workshop: Developing a Circular Economy through Industrial Symbiosis in Belarus

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What and Why?

- Collective input from participants (experts)
- Share information internationally
- Background to output report
- Collaborate/Create Interaction
- Kick-Start/Create/Establish Starting point for further collaborative efforts
- Promote IS/CE in Belarus

Your thoughts and ideas for identifying

- Current initiatives (industrial symbiosis networks, material and energy synergies, circular economy initiatives, etc.)
- Possible future synergies based on knowledge of industrial development
- Important sectors and firms to explore further
- Possibilities and barriers for IS in Belarus
- How can these possibilities and barriers be overcome?
- Required stakeholders for IS/CE development
- Your needs to develop IS

Current IS/CE Innitiatives and Improvement Potential

- Identify examples of IS networks in Belarus
- Potential synergies between firms/sectors
- What improvement potential is there?
- What important sectors are there?
- What regions would be most suitable?

Barriers and Possibilities for IS Development

- What drivers are there?
- What level of knowledge is there amongst stakeholders of IS and CE?
- What barriers do you see? (Political, institutional, technical, etc.?)
- How can barriers be overcome/drivers strengthened?

Needs , Requirements and Experience?

- What would be required to start IS networks regionally?
- What competences are needed?
- What stakeholders need to be involved?
- What information is necessary to ensure symbiotic development?
- What are your experiences?

Plan/Timeplan

- Split into 3 groups
- First take 5 minutes alone to write down some thoughts on Post-its
- Take 20 minutes to present and group these throughts into similar themes (if possible) and add to your sheet
- After discussing, please move around to other groups, discuss and interact
- Add to the other sheets if you feel there is anything missing and required

Groups/Leading Questions

Current IS/CE Innitiatives and Improvement Potential	Barriers and Possibilities for IS Development	Needs , Requirements and Experience?
• Are there current IS networks/synergies between firms you know of? • What initiatives for new developments are there? • What new synergies can you envision? • What sectors/important firms?	• What drivers are there for IS/CE in Belarus? • What level of knowledge is there amongst stakeholders? • What barriers do you see? • Who can barriers be overcome/drivers strenthened?	• What stakeholders need to be involved? • How can they be led? • What information is necessary to ensure symbiotic development? • What is needed? • What are your experiences?

Please work and interact